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Sewer Flow Measurement A State-of-the-Art Assessment

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November 1975

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A brief review of the characteristics of storm and combined sewer flows is given, followed by a general discussion of the need for such flow measurement, the types of flow data required, and the time element in flow data. A discussion of desirable flow measuring equipment characteristics presents both equipment requirements as well as desirable features and includes an equipment evaluation sheet that can be used for a particular application. A compendium of over 70 different generic types of primary flow measurement devices, arranged according to the fundamental physical principles involved, is presented along with evaluations as to their suitability for measurement of storm or combined sewer flows. To illustrate the implementation of the physical principles, a number of commercially-available devices for flow measurement are briefly described. A review of project experience in flow measurement is presented along with a summary of current and on-going research efforts. Some thoughts on future areas of research and development are also given.

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SEWER FLOW MEASUREMENT - A STATE-OF-THE-ART ASSESSMENT

by

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise, and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The Municipal Environmental Research Laboratory contributes to this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

The deleterious effects of storm and combined sewer overflows upon the nation's waterways have become of increasing concern in recent times. Efforts to alleviate the problem depend upon accurate characterization of these flows in both a quantity and quality sense. This report presents a state-of-the-art survey of flow measuring devices and techniques that either are, or might be, appropriate for the quantitative measurement of stormwater and combined sewer flows as well as other wastewater discharges, and will be of interest to those who have a requirement for the measurement of such flows.

ABSTRACT

A brief review of the characteristics of storm and combined sewer flows is given, followed by a general discussion of the need for such flow measurement, the types of flow data required, and the time element in flow data. A discussion of desirable flow measuring equipment characteristics presents both equipment requirements as well as desirable features and includes an equipment evaluation sheet that can be used for a particular application.

A compendium of over 70 different generic types of primary flow measurement devices, arranged according to the fundamental physical principles involved, is presented along with evaluations as to their suitability for measurement of storm or combined sewer flows. To illustrate the implementation of the physical principles, a number of commercially-available devices for flow measurement are briefly described.

A review of selected U.S. Environmental Protection Agency project experience in flow measurement is presented along with a summary of current and on-going research efforts. Some thoughts on future areas of research and development are also given. This report was submitted in fulfillment of Contract Number 68-03-0426 under the sponsorship of the Office of Research and Development, U.S. Environmental Protection Agency. Work was completed in December 1974.

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SECTION I

CONCLUSIONS

1. A flowmeter is one tool of several that must be employed for the characterization of a wastewater stream. Its selection must be based upon consideration of the overall flow measurement program to be undertaken, the nature of the flows to be measured, the physical characteristics of the flow measurement sites, and the degree of accuracy required, among other factors.

2. In view of the large number of highly variable parameters associated with the storm and combined sewer application, no single flowmeter can exist that is universally applicable with equal efficacy. Some requirements are conflicting, e.g., an open drainage ditch versus a closed conduit deep underground, and a careful series of trade-off studies is required in order to arrive at a "best" selection for a particular program and site.

3. There are over 70 generic devices and methods that can be used for determining wastewater flows, and they were reviewed and discussed.

4. The proper selection of flow measurement sites can be as important as the selection of methods and equipment. A clear understanding of the data requirements and ultimate use is necessary, as is a familiarity with the sewer system to be examined.

5. Of the over 120 prospective manufacturers of liquid flow measuring equipment which were contacted, none has a flow measurement product line that is specifically designed for the storm and combined sewer application.

6. Where large flows are to be measured with fairly high accuracy, considerable expense in terms of initial equipment cost, site preparation and installation, and operator training and maintenance is involved; fifty to one hundred thousand dollars should not be considered atypical.

7. There are measurement sites where no presently available equipment can operate unattended for long at a high degree of accuracy (better than ±5% of full scale).

8. The most consistently reliable flow measurement data have been taken at sites where the equipment has been calibrated in place over the entire range of flows anticipated.

9. Field experience in wastewater flow measurement was reviewed, and in most instances errors of greater than 10% seem to be the rule. It is not at all uncommon to find readings that differ from spot field checks by from 50 to 200 percent. Some wastewater discharge data are of such poor quality as to be virtually useless.

10. Flow measurement research efforts within the United States were reviewed. Very few of those outside the USEPA are addressed to the storm and combined sewer problem as presented here, and it would appear that few, if any, that are not so oriented will produce technology fall-outs that will benefit the solution of the problem at hand.

11. The technological state-of-the-art, especially in electronics, is advancing very rapidly at the present time, and capabilities are emerging that until now were either impossible or prohibitively expensive. Examples include improved pressure sensors, solid state and integrated circuitry advances (and price reductions) that facilitate control and computational functions, quartz crystal timers that offer accuracy improvements measured in orders of magnitude, improvements in electronic recorders, etc. As a result, both new products and improvements to old ones are continually appearing.

SECTION II

RECOMMENDATIONS

1. It is recommended that flow measurement accuracy requirements be very carefully considered with an eye to optimizing the accuracy of determination of total pollutant discharge. Very high accuracies over very wide ranges may not be necessary for all purposes and will certainly be expensive to achieve.

2. Where possible, it is recommended that flow measurement equipment be calibrated in place at the site where the data are to be collected. Maintenance should be performed such that conditions do not deviate greatly from those at the time of calibration.

3. Use and maintenance of complex, sophisticated flow measurement equipment should not be entrusted to well-meaning but untrained personnel. Proper training of operator personnel is recommended as it will produce long-term benefits.

4. It is recommended that the flow measurement site be chosen with great care. It can be as poor an error in judgement to choose a site that will not yield the desired data simply because of equipment availability as it is to attempt to apply the wrong equipment at a site that is truly important.

5. In view of the immediate requirements for storm and combined sewer discharge data for surveys, computer model calibration and verification, infiltration/inflow studies, and the like, the most urgent need is for suitable portable devices that are capable of unattended operation. It is strongly recommended that a program to develop such devices be initiated with special emphasis on:

    - Automated Chemical Dilution Devices

    - Ultrasonic Devices

    - Hybrid Flumes

6. There has been very little opportunity to evaluate flow measurement equipment suitable for storm and combined sewer applications in a side-by-side fashion under somewhat controlled conditions. It is strongly recommended that a suitable facility be identified and used to gather comparative data with emphasis on the more promising portable devices.

7. There are a number of flow measurement devices that have either recently become available or are about to be introduced and that offer considerable promise in a storm and combined sewer application. It is recommended that a program of demonstration testing be initiated to include such devices as:

    - Venturi Meter/Flumes
    - Combination Thermal Flowmeters
    - High Range Open Flow Nozzles

8. This study was essentially limited to developments and practices within the United States. It is recommended that a survey of foreign research and development activities and storm and combined sewer flow measurement practices be conducted.

9. Because of the burgeoning nature of the present state of the art and increasing concern over environmental contamination caused by storm and combined sewer discharges, this report should not be considered a final, enduring document. It is recommended that it be expanded and updated within two years.

SECTION III

INTRODUCTION

Since almost the beginning of civilization, man has recognized the need to determine liquid flow rates, quantities, or stages, and his first efforts were probably directed towards survival during floods and transportation by water craft. Demands for water supply, irrigation, navigation, and waterpower all accentuated the need for flow measurement. It is known that the ancient Babylonians and Egyptians used some means of water accounting to individual land holders from their extensive irrigation systems. The procedures used were possibly taken from methods used earlier in eastern Asia.

The River Nile of Egypt has probably been studied for a longer period of time than any other river in the world. The crops of the Nile Valley are dependent upon annual flooding by the river, and thus, annual yields are proportional to fluctuation in stage. In view of this, taxes were levied based upon maximum flood height. An interesting compilation of data concerning flood records of the Nile has been prepared by Jarvis (1). Mention of the annual rises of the Nile date back to between 3000 and 3500 B.C., and known flood marks extend as far back as approximately 1800 B.C.

One of the most complete records of early flow measurement systems is that by Sextus Julius Frontinus (2), who was the Water Commissioner of Rome in the latter part of the first century. The quantity of water delivered to each user in the Roman system was determined entirely on the area of spouts through which the flow was discharged; thus, these could be considered as early forms of flow nozzles.

The earliest attempts at flow velocity measurement were undoubtedly made by timing the travel of floating debris over some measured distance. Hero of Alexandria's proposal, which was written about 62 A.D., called for using a sun dial for timing his operation. In the 15th Century, Leonardo da Vinci offered an improvement by attaching an inflated pig's bladder to one end of a pole and a stone to the other, thus achieving an integrating float of sorts. Frazier (3) provides an interesting account of a physician's plan for a deflection water current meter, circa 1610. In the middle of the 17th Century, Evangelista Torricelli developed the relation that the rate at which water was discharged from an orifice varied with the square root of the height of the water surface in the supply tank. Subsequent improvements in the state of the art included Henri Pitot's impact tube developed in 1732, Reinhard Woltman's propeller-type current meter invented around 1790, and the work of Giovanni Venturi on the relations between the velocities and pressures of fluids flowing through converging and diverging tubes reported in 1797.

The history of improvements in flow measurement devices/techniques is far too extensive to be reported here. The reader interested in the subject is referred to some of the selected additional references listed in Section XI. It suffices to say that today we have a plethora of liquid flow measurement devices and techniques available, and it is to them that the remainder of this report will be directed.

PURPOSE AND SCOPE

Among man's first waterworks projects were aqueducts to convey water into his cities for consumption and sewers to collect and dispose of nuisance stormwater. As early urbanization continued, these first storm drains also became the transport media for domestic wastewater and, in effect, the first combined sewers. For convenience and expediency, these sewers simply emptied into the nearest natural watercourse. As urbanization continued, the dry-weather flow in these sewers became a public nuisance, and wastewater treatment was born. Sanitary engineering practices and procedures were developed, all based upon characterizing and treating this dry-weather or sanitary sewage flow. The construction of separate storm and sanitary sewer systems in many cities was merely an extension of this trend. The pollutional characteristics of stormwater were unrecognized, and it continued to be simply discharged into the nearest natural stream.

The phenomenal growth of urban areas in recent times and the rapid expansion of industrial operations to meet society's ever increasing demands for more goods, energy, etc., have heightened the pollutional potential of man's existence and have contributed to his increasing awareness of and concern for his environment. One of the impacts of the population explosion is that sanitary engineering practices that appeared tolerable even as recently as a few decades ago are no longer acceptable today in many locales. The pollutional effects of stormwater and combined sewer overflows on receiving water quality are becoming less and less tolerable and a research program to mitigate or ameliorate the situation has been underway at the USEPA (and its predecessor agencies) for the last several years.

In order to characterize these stormwater and combined sewer overflows and to facilitate the development, demonstration, and evaluation of treatment and control systems for combating the problem, it is necessary to have available accurate and reliable means of determining the quantity and quality of the flows in question. Both the quantity and quality of urban stormwater runoff are highly variable and transient in nature, being dependent upon meteorological and climatological factors, topography, hydraulic characteristics of the surface and subsurface conduits, the nature of the antecedent period, and the land use activities and housekeeping practices employed. Conventional flow measurement devices and techniques have been developed mainly for the relatively steady-state flows as found in irrigation canals, sanitary sewers, and large streams and not for the highly varying surges encountered in storm and combined sewers.

This report is intended to present a current review of the state of the art and assessment of flow measurement devices and techniques. These are described and evaluated in terms of their suitability for use in storm and combined sewer applications. However, a device or technique which is suitable for such use will most likely suffice for any other wastewater flow measurement application as well. By collecting and presenting such a review, it is hoped that shortcomings and limitations of some extant devices and techniques for storm and combined sewer applications can be overcome and that this report can serve as a springboard for improvements.

GENERAL NATURE OF STORM AND COMBINED SEWER FLOWS

Storm Sewer Flows

Although storm sewers are basically designed to carry storm runoff, during periods of no rainfall they often carry a small but significant flow (dry weather flow). This may be flow from ground water, or "base flow", which gains access to the sewer from unpaved stream courses. Such base flow may appear as runoff from parks or from suburban areas where there are open drains leading to the storm sewer. Unfortunately, much of the dry weather flow in storm sewers is composed of domestic sewage or industrial wastes or both. Where municipal ordinances concerning connections to sewers are lax or are not rigidly enforced, it appears reasonably certain that unauthorized connections to storm sewers will appear. In some cases, the runoff from septic tanks is carried to them. Connections for the discharge of swimming pools, foundation drains, sump pumps, cooling water, and pretreated industrial process water to storm sewers are permitted in many municipalities and contribute to flow during periods of no rainfall. In some areas, sewers classed as storm sewers are, in fact, sanitary or industrial waste sewers due to the unauthorized or inappropriate connections made to them. This may become so aggravated that a continuous flow of sanitary or industrial wastes, or both, flows into the receiving stream.

The "dry-weather" portion of storm sewer flow may vary significantly with time. Probably the most steady flow, and constant character of pollutants therein, occurs in storm sewers when all flow is base flow derived from ground water. Because of the slow movement of water through the ground, changes in flow and concentration of pollutants occur only during relatively long time periods. Where unauthorized connections of domestic sewage and industrial waste lines to storm sewers are found, rapid fluctuations with time may occur. The domestic sewage constituent varies with time of day, with season of year, and probably over long-term periods. Industrial wastes vary with specific processes and industries. Very rapid changes may occur with plant shift changes and with process dynamics. Conditions on weekends and holidays may be very different from those on regular work days.

Storm runoff is the excess rainfall which runs off the ground surface after losses resulting from infiltration to ground water, evaporation, transpiration by vegetation, and ponding occur. A small portion of the rainfall is held in depression storage, resulting from small irregularities in the land surface. The quantity, or rate of flow, of storm runoff varies with intensity, duration, and areal distribution of rainfall; character of the soil and plant life; season of the year; size, shape and slope of the drainage basin; and other factors. Ground seepage loss varies during the storm, becoming less as the ground absorbs the water. The period of time since the previous, or antecedent, rainfall significantly affects the storm runoff.

In general, storm runoff is intermittent in accordance with the rainfall pattern for the area. It is also highly variable from storm to storm and during a particular storm. The time-discharge relationship, or hydrograph, of a typical storm, with its synchronous time-precipitation relationship, or hyetograph, is illustrated in Figure 1. The meanings of various parameters given in the figure are:

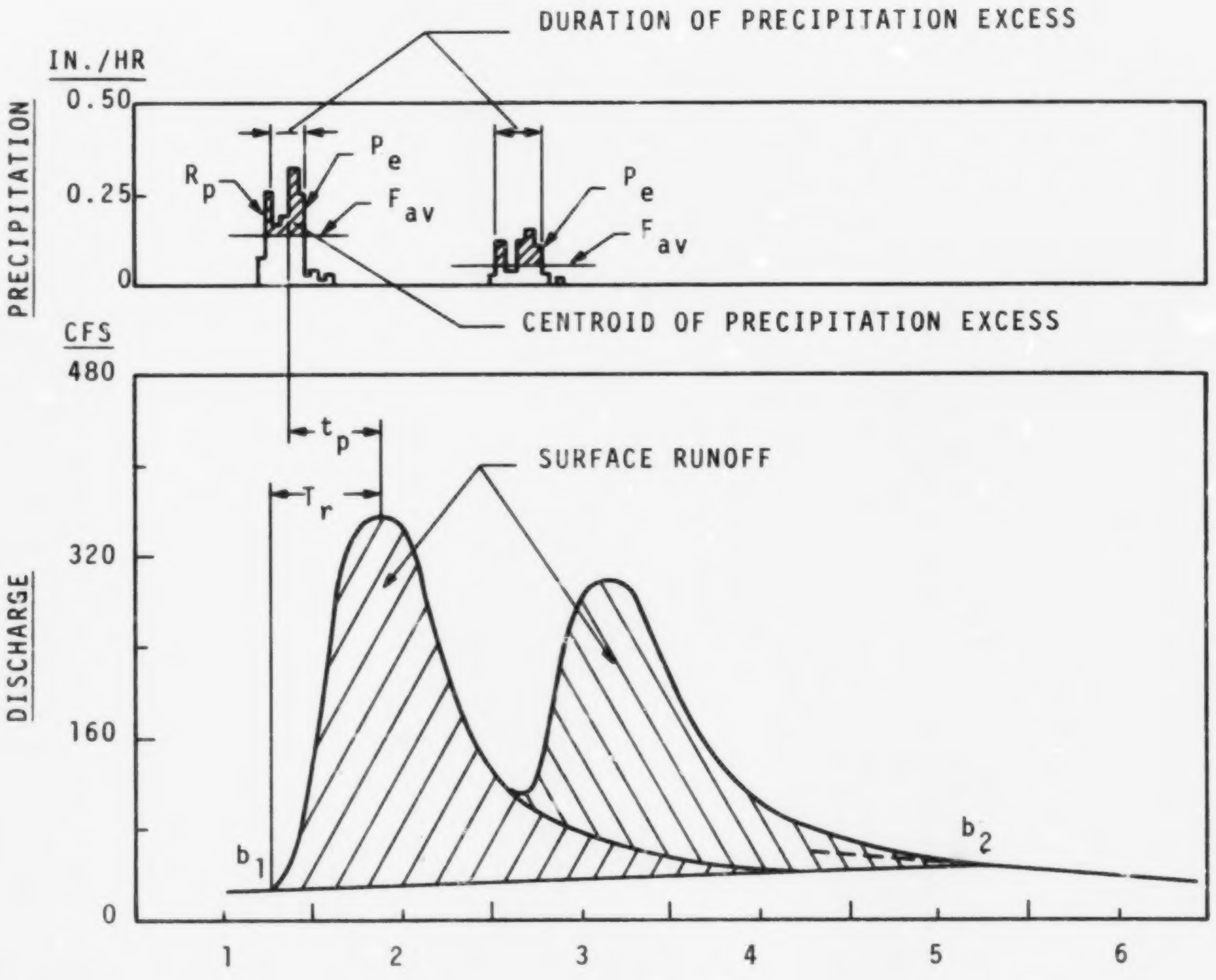
R_p - Rainfall retained on the permeable portion of the drainage basin, and not available for runoff.

P_e - Precipitation in excess of that infiltrated into the ground, plus that retained on the surface. Equals the volume of flood runoff.

F_{av} - Average infiltration of the ground during the storm. Infiltration capacity decreases as the storm progresses.

T_r - Period of rise from the beginning of storm runoff to peak of the hydrograph.

T_p - Time from center of gravity of rainfall excess to the hydrograph peak (lag time).



LEGEND: 1 INCH = 2.54 CM
1 CUBIC FOOT = 28.3 LITERS

Figure 1. Typical Storm Hyetograph and Hydrograph

b_1, b_2 - Base line separating groundwater discharge from surface runoff.

The total volume of runoff for a particular storm is represented by the areas between the base line and the hydrograph.

To illustrate some of the problems in measuring storm runoff in small basins, peak flows exceeding 85 cubic meters per second per 260 hectares (3,000 cfs per square mile) have been observed. Lag times (t_p), for example, of 15 minutes to a hydrograph peak of about 28 cubic meters per second (1000 cfs) from a 600-hectare (2.3 sq mi) area are not uncommon. With rapid changes in the flow such as this, only those flow measurement methods which are responsive to such changes can be used. The high rates of flow, with accompanying high velocities, further limit the usable flow measuring equipment methods.

The maximum rate of flow in an underground storm sewer is governed by its design capacity. This capacity is based on the flow due to a storm occurring, on the average, once in a selected number of years (recurrence interval). Usually, a recurrence interval not greater than 10 years is selected for the design of underground storm sewers. As a result, the design capacity of the sewer is sometimes exceeded, resulting in surcharging and flooding of the overlying surface. Under these conditions, measurement of surface flow must be added to measurement of surcharged flow in the sewer to obtain total flow.

The poor quality of stormwater draining from the urban environment has a significant effect on the choice of suitable flow measurement equipment and methods. Washings from the sidewalks, streets, alleys, and catch basins are a part of the runoff and include significant amounts of human and animal refuse. In industrial areas, chemicals, fertilizers, coal, ores, and other products are stockpiled exposed to rainfall, so that a significant quantity of these materials appears in the runoff. Extreme quantities of organic materials such as leaves and grass cuttings often appear in storm sewers. Often during storms large boards, limbs, rocks, and every imaginable kind of debris appear in the sewers, probably as a result of breaks in the sewers or accessory equipment designed to screen out the larger items.

Observation and experience have demonstrated that the heaviest concentration of suspended solids during periods of storm runoff usually occurs during the early part of the storm. At this time, the stage is rising, and accumulated dry-weather solid residue is being flushed from the sewers and washed and eroded from the tributary land areas. As runoff recedes, the sewer and land area surfaces exposed to flow are reduced; the flow velocities which serve to flush and erode are decreased; and the more easily dislodged solids have been acted upon.

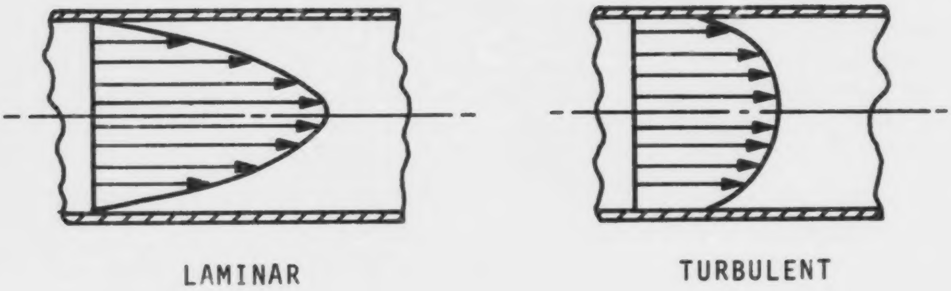
This pattern of variation may not occur during a period of storm runoff which immediately follows a previous storm runoff period because the land surface and sewer lines are relatively clean.

Pollutants which may be injurious to equipment, and are derived from point sources such as those from stockpile drainage, vary at the sampling location with time of travel from the source to the point of observation. Maximum concentration may occur after the peak of storm runoff. It is conceivable that there would be no contribution from some point sources during a specific storm because of areal variation of rainfall in the basin.

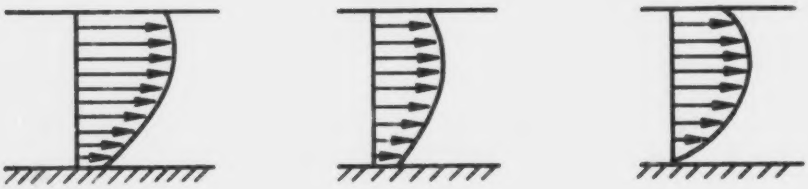
Both velocity and the concentration of suspended solids in storm sewers vary with position in the sewer cross-section. The manner in which velocity is distributed in the sewer section seriously affects those flow measurement methods which require independent determination of average velocity. Some typical velocity profiles are shown in Figure 2. With open-channel flow, higher velocities are usually found near the surface and lower velocities near the bottom. Average velocity in the vertical is at about 0.6 depth. Velocities are higher near the center of the pipe or conduit than near the outer boundaries. When the conduit is surcharged and is flowing full, lines of equal velocity tend to be concentric, with the higher velocity near the center. On horizontal curves, higher velocities are on the outside of the curve due to the centrifugal inertia force. Because the effect of curvature on flow often continues downstream for a considerable distance, a normal distribution of velocity is not found on a curve, or downstream for a distance of several sewer widths.

Suspended solids heavier than water have their lowest concentration near the surface, and the concentration increases with depth. A "bed load", composed almost entirely of heavier solids, may occur near the bottom of the sewer. This may "slide" along the bottom or, with insufficient flow velocity, may rest on the bottom. As the velocity and turbulence increase, the "bed load" may be picked up and suspended in the sewage. At the beginning of storm runoff, as water picks up solids which have accumulated in the sewer upstream during periods of no rainfall, the flow may be composed largely of sewage solids, or bed load, which appears to be pushed ahead by the water.

Suspended materials lighter than water, such as oils and grease, float on the surface - as do leaves, limbs, boards, and some cloth and paper materials. Other small, light particles are moved randomly within the flow by turbulence. Larger, heavier suspended and floating solids tend to move to the outside of a horizontal curve, following the stream lines of higher velocity.


LAMINAR
TURBULENT

a) FULL PIPE FLOWING UNDER PRESSURE



b) SOME OPEN CHANNEL FLOW PROFILES

Figure 2. Typical Vertical Velocity Profiles

Combined Sewer Flows

Combined sewers are designed to carry both stormwater and sanitary sewage and/or industrial wastes. Therefore, except for their sanitary and industrial sewage components (dry-weather flow), they have the same flow characteristics as storm sewers. As indicated earlier, where municipal ordinances are lax or not enforced with respect to sanitary or industrial sewer connections to them, storm sewers are little different from combined sewers. As combined sewers are designed, dry-weather flow generally includes only a small portion of the total sewer flow. However, due to overloading in many rapidly developing areas, the dry-weather flow sometimes requires a much larger percentage of total capacity. Furthermore, stormwater runoff usually increases dramatically with urbanization.

Because the design, or available, capacity of combined sewers for carrying stormwater is probably less than is usually provided in storm sewers, they either become surcharged more frequently, or the excess flow is diverted to overflow lines.

NEED FOR FLOW MEASUREMENT

Measurements of quantity of flow, usually in conjunction with sampling for flow quality, are essential to nearly all aspects of water pollution control. Research, planning, design, operation and maintenance, and enforcement of pertinent laws - all are activities which rely on flow measurement for their effective conduct. For some activities, very precise, time synchronized, continuous flow records are needed. With others, occasional, fairly rough estimates of flow may suffice.

Research

A principal research activity is the development of an extensive backlog of data to characterize the various types of wastewater - e.g., sanitary and industrial wastes, stormwater, combined sewage, and effluents from treatment plants. The quantity and rate of sanitary sewage flow from individual homes, apartments, and commercial buildings, as found in various cities and geographic locations, provide data useful for many purposes. Similarly, measurement of the flow of wastes from specific industrial processes provides general information concerning the character of such industrial wastes. Characterization of stormwater and combined sewage with respect to geographic location, population density, land use, and other parameters, makes reasonably accurate estimation for unmeasured areas possible. Similarly, flow records from a network of natural streams throughout the country, such as those maintained by the U.S. Geological Survey, make possible the characterization of ungaged streams which may be required to receive wastewaters.

Mathematical models of the relationships between rainfall, runoff, basin characteristics, and concentration of pollutants in the runoff, such as the Storm Water Management Model of the USEPA, are being developed. The principal limiting factor in the development and testing of such models has been the scarcity of satisfactory data on the quantity and quality of runoff in urban areas. Although these models can perform a very useful function in synthesizing flow records, they do not fully substitute for actual flow measurements and records. For example, application of a model to an unfamiliar area needs verification by actual records, and adjustments to the model are often indicated.

Planning

The availability of reasonably accurate and long-term records of flow is a basic requirement for planning new or expanded systems of sewers, or systems for the control and/or treatment of stormwater and combined sewage. Such records, with records of water quality, are required to define the scope of the problem to be solved, and to make necessary decisions concerning the type, size, number, and location of facilities required.

A knowledge of existing flow conditions, plus knowledge of existing pollutant concentrations, is indicative of conditions to be expected in the future, and thus serves to define the problem. For example, infiltration into sewers is a common problem which must be addressed to avoid excessive construction and operational costs. Flow measurements can serve to locate the approximate source and quantity of such infiltration.

For storm and combined sewer systems, knowledge of the number, frequency, and pollutant loadings (the product of quantity and concentration) of overflows is necessary to evaluate their impact on the receiving stream. Thus, the extent and seriousness of the problem can be determined.

In many cases, the sources and movement of stormwater pollutants are not obvious. They may originate partly through rain and snowfall over a city; from the surfaces of buildings, streets, vacant land, construction sites, parking lots, and yards in urban runoff; and in the sewer system. Often the sources and movements of such pollutants can be determined through a systematic program of flow measurement and sampling, thus outlining the necessary extent of a pollution control system or program.

A significant number of procedures and facility types are available to management for the control of pollution due to stormwater and combined sewage. In general, these include methods for controlling the quantity of flow, and those for treating, or improving the quality, of wastewater.

Quantity of stormwater can be controlled at the source by increasing infiltration to groundwater, and can be controlled in the sewer system itself by reducing infiltration to the system, by using the maximum capacity of the system itself for storage, and by other procedures. Facilities for temporary storage of wastewater outside of the sewer system can be provided.

A number of physical, chemical, combinations of physical-chemical, and biological methods have been considered in the Storm and Combined Sewer Pollution Control Program of the USEPA for treatment of stormwater and combined sewage. In most cases, some type of control such as reduction of instantaneous peak flows is essential for practical application of treatment methods. Selection of suitable facilities and procedures for control of peak flows depends upon the availability of storm hydrograph records.

Character of storm runoff as influenced by geographic differences in storm patterns, intensity, and frequency is defined by records of flow and is the basis for decision on the type of pollution control system to be used. As stated by Lager and Smith (5), *"Storms of high intensity and short duration may be best countered with storage, whereas storms of low intensity and long duration may be more effectively controlled through increased treatment capacity or runoff deterrents such as porous pavements. Intervals between storms are significant in that they may dictate dewatering requirements and, in turn, treatment rates in system cleanup from one storm in preparation for the next."*

Design

Design of facilities for temporary storage of wastewater within the sewer system - such as flow control structures, and off-line storage facilities - must be based largely on records of peak flows and storm hydrographs. Such data are often most useful when converted to figures of frequency of peak flows or of runoff volume-duration-frequency. The probability of a second storm occurring within a selected time interval is also useful in sizing storage facilities. It should be recognized that wastewater pollution control facilities can, in most cases, be designed to handle runoff only from storms of comparatively short recurrence intervals. Runoff from larger storms, of relatively infrequent recurrence intervals, may completely submerge the facility and surrounding area, and the only design concern would be protection from damage.

If, for example, screens are to be used for treatment, the number and size of units, size of screen openings, and other design characteristics (such as frequency of screen cleaning) must depend largely on the rate and volume of wastewater flow to be handled and on the concentration of pollutants. Similarly, if chemical treatment is to be used, the number and size of units, the quantity of chemicals, and the design of equipment for chemical handling must be based on records of peak flow and volume of flow, as modified by storage.

Operation and Maintenance

Although operational guides and maintenance procedures are often based on historical records of flow, flow records obtained on a "real-time" basis may be more useful for operational purposes. Where temporary storage within an extensive system of sewers is controlled by computer, flows at remote locations may be sensed and telemetered to the computer. The system can thus be regulated to more fully utilize its total capacity. If temporary offline storage is to be utilized within a combined sewer system, a preselected rate of flow, or stage, in the sewer could serve to initiate diversion to storage. Efficient operation of systems for wastewater pollution control must depend upon measurement and sampling of flows. In fact, operation of the large-scale, high-rate systems that may often be required for control and treatment of stormwater and combined sewage will not be possible without coordinated systems of flow measurement and sampling.

Permits and Enforcement

Section 402 of the Federal Water Pollution Control Act Amendments of 1972 (6), "*...creates a National Pollutant Discharge Elimination System under which the Administrator of the Environmental Protection Agency may, after opportunity for public hearings, issue permits for the discharge of any pollutant or combination of pollutants, upon condition that such discharge will meet all applicable requirements of the Act relating to effluent limitations, water quality standards and implementation plans, new source performance standards, inspection, monitoring and entry provisions, and guidelines establishing ocean discharge criteria.*"

The Act requires that the Administrator of the USEPA prepare, and make public, a fact sheet for every permit application having a total discharge volume of more than 500,000 gallons on any day of the year. (The Administrator may prepare fact sheets for smaller discharges.) Included in the fact sheet must be: "*A quantitative description of the discharge described in the NPDES application which includes the rate or frequency of the proposed discharge; if the discharge is continuous, the average daily flow in gallons per day or million gallons per day;*"

Provision is made for enforcement of the Act by recourse to criminal, civil, and civil injunctive remedies. Thus, measurement of flow is one of the basic requirements for issuance of a permit to discharge pollutants.

TYPES OF FLOW DATA REQUIRED

Basic flow data can be classified in accordance with their probable accuracy, time continuity or discontinuity, and their general quantity level - such as high, medium, or low. All flow data must be synchronized with time, at least on a watch time basis, to have any useful meaning. For some purposes, such as certain research or operation functions, very precise time synchronization is necessary. To increase their usefulness, various statistical parameters such as totals, means, extremes, variability, and frequency are derived by analysis of the basic flow data.

Continuous records of flow for the time period of interest probably are most commonly required. For planning and design of pollution control facilities, or for determining the effects of pollution on the receiving stream, many years of continuous record of flow may be useful. Continuous "real-time" data for operation of facilities may be needed for an indefinite time period.

In many storm sewers, flow outside the periods of storm runoff is negligible. Therefore, the need is for continuous record of flow during periods of storm runoff only. Flow measurement equipment can be activated automatically by the onset of rainfall, or by preselected water surface elevation, and can be deactivated in a similar manner.

There may be situations where the magnitude and frequency of peak flows only would be required. These data could, for example, be required for determination of the maximum required size of sewers or other facilities. In this case, crest-stage measurements only can be obtained by various simple devices such as a vertical pipe stilling well with a graduated rod left in it. Maximum stage is recorded by a line of ground cork, or other floatable material, left on the stick during a period of storm runoff. A calibrated primary device, such as a culvert, flume, or rated channel, must be used with the crest-stage measuring equipment.

On the other hand, measurements of low flow only can be useful. This would be true in cases where low flow augmentation of the receiving stream could be an acceptable measure for reducing the concentration of pollutants in the stream. Because of the usual slow change in streamflow during periods of dry weather, comparatively few measurements are needed to define such low flows.

Another type of flow measurement, often known as a miscellaneous measurement, is made only at rather infrequent intervals of time. The time interval may be regular, or it may be simply at the convenience of the hydrographer. Such measurements are useful where flow is known to be relatively steady. Flows of effluent from treatment plants, effluent from selected types of industrial plants, sanitary sewage, or storm sewers during periods of dry weather may be satisfactorily defined by miscellaneous measurements.

Often, flow measurements are made for the purpose of calibrating another, possibly continuous type, flow measurement device. For example, a series of current meter measurements may be made over a range of stages to calibrate a measuring flume which may not be precalibrated satisfactorily.

The probable accuracy of flow data is determined by a number of factors. Each type of flow measurement equipment has an inherent maximum capability for accuracy. Care with which certain types of equipment are installed affects the accuracy of the flow data. Conditions under which the equipment is used influence the accuracy of the data collected. The harsh conditions found in many sewers can be detrimental to measuring equipment, and makes the work of the hydrographer difficult. Use of certain types of equipment necessitates considerable training and experience if accurate records are to result. Estimates of probable accuracy of the data should always be furnished by field personnel as a guide to the user, who otherwise has little means of knowing if they should be rated as excellent, good, fair, or poor.

SECTION IV

THE TIME ELEMENT IN FLOW DATA

Measurements of flow are useful only with respect to the relationship of the measured flow with other phenomena. An assignment of time of occurrence to flow data makes possible a determination of its relationship to other parameters whose times of occurrence are known. The other parameters of interest may or may not be synchronous with the flow data. In some cases, definition of the time interval between events is sufficient but, generally, the true clock time, preferably standard time, of the concerned flow is required.

IMPORTANCE OF THE TIME ELEMENT

The required accuracy of the time element in flow data is very different from requirement to requirement. An example is the use of peak flows for each year to determine their frequency. On the other hand, flows at intervals as short as one minute have been collected to define the discharge hydrograph from small urban areas.

A particular need for improved accuracy in the time element occurs in the measurement of flows from small urban storm sewers in order to define the hydrograph and to provide data for development and verification of rainfall-runoff-quality models. Accurate definition of both the time and discharge elements of the hydrograph makes possible the computation of total volume of runoff during the storm by computing the area under the hydrograph, exclusive of base flow. By selecting a number of well defined hydrographs resulting from storms of similar rainfall characteristics, a typical hydrograph for the basin can be defined. When the hydrograph is so adjusted that its runoff volume is 2.54 cm (1.00 in.) of rainfall excess, it is called a "unit hydrograph", and it can be conveniently used to define hydrographs resulting from similar rainfalls of any volume of rainfall excess. Shape of the unit hydrograph is determined by accurate timing as well as by discharge, although it is independent of clock time. The hydrograph as defined by clock time and discharge is often used to route flows along a stream channel or through a reservoir.

Peak flows, storm runoff volumes, daily flows, or other flow parameters are often correlated with similar flows at other points on a storm sewer or stream, or with flows of other storm sewers or streams, to provide a means for flow estimation. Also, correlations may be made with various physical characteristics of a basin, such as area, slope, population density, etc. Correlations with temperature, soil moisture, or antecedent precipitation may be made at times. In most cases, it is essential that the correlated variables be synchronous, so accurate timing of the data is often required.

Timing of measured flows and collection of quality samples can be useful in determining sources of pollution. For example, they can be related to time of release of pollutants from industrial plants, or to the time of accidental spills of pollutants. The time of travel of pollutants along a stream or storm sewer can be estimated from the time of travel of small rises or other flow changes in the channel.

In many situations where flow measurement is used for operation of pollution control facilities, accurate timing of the flows may be required. This is particularly true where upstream flow data are transmitted electronically for automatic control of gates, pumps, and other devices for the relief of stormwater flows.

CONTINUOUS RECORDING OF FLOWS

Many different kinds of equipment are available for the continuous recording of flow data. In general, they consist of a clock, or timer, which drives or regulates the rate of motion of a strip chart or tape, or a circular chart. Discharge may be recorded directly on the chart by pen, pencil, or digital punch; or, stage only may be recorded for later conversion to discharge by means of known relationships of stage to discharge. This conversion may be made manually, with the aid of a discharge integrator, or by means of a computer where digital punched tape is available.

Adjustments, or corrections, to the record are usually required. The clocks or timers in general use do not maintain fully accurate chart time. Sliding time corrections are made for the periods between visits when the chart position of the pen is compared with watch time of the hydrographer. Small errors in discharge or stage are similarly corrected for the periods between visits. Careful review of the charts may reveal periods of clock stoppage, temporary backwater conditions, or instrument malfunctions for which corrections may be made.

When the relationship between stage and discharge is nonlinear, rapidly changing stages must be subdivided into relatively short periods before converting to discharge. Due to intermittent use of daylight saving time, and inconsistent use of such time from place to place, all flow records should be adjusted to standard time.

Clock Drives and Timers

Clock drives commonly used on flow recorders include spring wound, suspended weight, battery powered motor, and synchronous motor (alternating current). Except for those driven by synchronous motor through a power system of regulated frequency, significant time errors can be expected. Errors of one or two hours per week are common with recorders of the 8-day type. Without careful clock adjustment, errors of several hours per month in continuous-type recorders are to be expected. Timers on the digital paper punches now widely used in the field by the U.S. Geological Survey are said to provide correct timing within about 15 minutes per month. Where required, more accurate timers are available to substitute for those in more general use. Extremely accurate time can be maintained with quartz crystal timers, for example. The cost of such solid state timers is not high, except for those having refinements such as compensation for error due to temperature change.

Synchronous data recording is often achieved by the tracing of more than one data parameter on a single chart controlled by a single timer. Thus, flow data may be traced together with rainfall data to provide a better relationship between rainfall and runoff. On one existing project, flow data from several sites are being transmitted to a central location and traced on a single chart. Although the data thus recorded are synchronous, they are not necessarily plotted to correct clock time. In several systems of combined sewers, "real-time" rainfall, quality, and flow data are transmitted to a central computer, which analyzes the data to provide control of gates, pumps, and regulators for optimum system operation.

Recorder Charts and Tapes

Difficulty in recording the correct time of flow data arises not only from error of timers, but also from mechanical inaccuracies in the recorders, and from nonconstant dimensions of the recorder paper. Under moist, humid conditions, most paper charts expand a significant amount. Expansion of more than 0.5 percent is to be expected at times. Error due to expansion of a strip chart could thus be one hour (or more) in 10 days of operation. A recorder with an auxiliary pen that marks the paper at uniform intervals of clock time, rather than relying upon preprinted time divisions on the chart, serves as a basis for correction due to humidity effects.

Timing of digital paper tape punch recorders is not affected by changes in the paper tape length because the punches occur at uniform intervals of clock time.

NONCONTINUOUS FLOW DATA

Other flow measurements, such as the miscellaneous type, are usually made directly by the hydrographer and are timed by his watch. It is important that he maintain his watch as accurately as possible, and that he note the time as standard or daylight saving, whichever it may be.

It is neither possible, nor necessary, to determine the precise time for crest-stage measurements of peak flows obtained as described above. Usually, the time can be established closely enough for the purpose by comparison with the corresponding peak stage at a nearby flow recording site.

SECTION V

DESIRABLE EQUIPMENT CHARACTERISTICS

From the brief review of the severe conditions and vagaries of storm and combined sewer flow and discussions given in the preceding sections, it is intuitively obvious that a number of very stringent design requirements must be placed on flow measurement devices if they are to function satisfactorily in such an application. It should also be apparent that no single design can be considered ideal for all flow measurement activities in all storm and combined sewer flows of interest. Characteristics of the available sites, as well as the particular flows in question, make a device that might be acceptable for one location totally unsuitable for another. Despite this, one can set forth some equipment "requirements" in the form of primary design goals and some desirable equipment features in the form of secondary design goals.

PRIMARY DESIGN GOALS

The following are considered to be primary design goals for equipment that is to be used to measure storm and combined sewer flows:

Range - Since flow velocities may range from 0.03 to 9 meters per second (0.1 to 30 fps), it is desirable that the unit have either a very wide range of operation; be able to automatically shift scales; or otherwise cover at least a 100 to 1 range.

Accuracy - For most purposes, an accuracy of ±10% of the reading at the readout point is necessary, and there will be many applications where an accuracy of ±5% is highly desirable. Repeatability of better than ±2% is desired in almost all instances.

Flow Effects on Accuracy - The unit should be capable of maintaining its accuracy when exposed to rapid changes in flow; e.g., depth and velocity changes in an open channel flow situation. There are instances where the flows of interest may accelerate from minimum to maximum in as short a time period as five minutes.

Gravity and Pressurized Flow Operation - Because of the conditions that exist at many measuring sites, it is very desirable that the unit have the capability (within a closed conduit) of measuring over the full range of open channel flow as well as with the conduit flowing full and under pressure.

Sensitivity to Submergence or Backwater Effects - Because of the possibility of changes in flow resistance downstream of the measuring site due to blockages, rising river stages including possible reverse flow, etc., it is highly advantageous that the unit be able to continue to function under such conditions or, at a minimum, be able to sense the existence of such conditions which would lead to erroneous readings.

Effect of Solids Movement - The unit should not be seriously affected by the movement of solids such as sand, gravel, debris, etc. within the fluid flow.

Flow Obstruction - The unit should be as nonintrusive as possible to avoid obstruction or other interference with the flow which could lead to flow blockage or physical damage to some portion of the device.

Head Loss - To be usable at a maximum number of measurement sites, the unit should induce as little head loss as possible.

Manhole Operation - To allow maximum flexibility in utilization, the unit should have the capability of being installed in confined and moisture-laden spaces such as sewer manholes.

Power Requirements - The unit should require minimum power at the measuring site to operate; the ability to operate on batteries is a definite asset for many installations.

SECONDARY DESIGN GOALS

The following are desirable features for flow measuring equipment, especially for use in a storm or combined sewer application:

Site Requirements - Unit design should be such as to minimize site requirements, such as the need for a fresh water supply, a vertical drop, excessive physical space, etc.

Installation Restrictions or Limitations - The unit should impose a minimum of restrictions or limitations on its installation and be capable of use on or within sewers of varying size.

Simplicity and Reliability - To maximize reliability of results and operation, the design of the unit should be as simple as possible, with a minimum of moving parts, etc.

Unattended Operation - For the majority of applications, it is highly desirable that the equipment be capable of unattended operation.

Maintenance Requirements - The design of the equipment should be such that routine maintenance is minimal and troubleshooting and repair can be effected with relative ease, even in the field.

Adverse Ambient Effects - The unit should be unaffected by adverse ambient conditions such as high humidity, freezing temperatures, hydrogen sulphide or corrosive gases, etc.

Submersion Proof - The unit should be capable of withstanding total immersion without significant damage.

Ruggedness - The unit should be of rugged construction and as vandal and theft proof as possible.

Self Contained - The unit should be self contained insofar as possible in view of the physical principles involved.

Precalibration - In order to maximize the flexibility of using the equipment in different settings it is desirable that it be capable of precalibration; i.e., it should not be necessary to calibrate the system at each location and for each application.

Ease of Calibration - Calibration of the unit should be a simple, straightforward process requiring a minimum amount of time and ancillary equipment.

Maintenance of Calibration - The unit should operate accurately for extended periods of time without requiring recalibration.

Adaptability - The system should be capable of: indicating and recording instantaneous flow rates and totalized flows; providing flow signals to associated equipment (e.g., an automatic sampler); implementation of remote sensing techniques or incorporation into a computerized urban data system, including a multisensor single readout capability.

Cost - The unit should be affordable both in terms of acquisition and installation costs as well as operating costs, including repair and maintenance.

EVALUATION PARAMETERS

It is, of course, not necessary that all of the primary and secondary design goals be achieved for all flow measurement requirements. For example, "spot" measurements of all flow rather than continuous records are sufficient at times. Flow measurement devices used to calibrate others need not necessarily be self contained, nor would unattended operations be required. Furthermore, meeting all of the listed design goals for all installations and settings would be difficult, if not impossible, to achieve in a single design.

Nonetheless, the primary and secondary design goals can be used to formulate a set of evaluation parameters against which a given design or piece of equipment can be judged. Since application details may make certain parameters more or less important in one instance or another, no attempt has been made to apply weighting factors or assign numerical rank. It is hoped that the evaluation factors will prove useful, as a check list among other things, for the potential user who has a flow measurement requirement and who may require assistance in the selection of his equipment.

The evaluation parameters, together with qualitative scales, are presented in the form of a flow measurement equipment checklist in Table 1.

TABLE 1. FLOW MEASUREMENT EQUIPMENT CHECKLIST

Designation: ____

Evaluation Parameter		Scale			Weight and Score
1	Range	☐ Poor	☐ Fair	☐ Good	
2	Accuracy	☐ Poor	☐ Fair	☐ Good	
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☐ Slight	
4	Gravity & Pressurized Flow Operation	☐ No		☐ Yes	
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☐ Low	
6	Effect of Solids Movement	☐ High	☐ Moderate	☐ Slight	
7	Flow Obstruction	☐ High	☐ Moderate	☐ Slight	
8	Head Loss	☐ High	☐ Medium	☐ Low	
9	Manhole Operation	☐ Poor	☐ Fair	☐ Good	
10	Power Requirements	☐ High	☐ Medium	☐ Low	
11	Site Requirements	☐ High	☐ Moderate	☐ Slight	
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☐ Slight	
13	Simplicity and Reliability	☐ Poor	☐ Fair	☐ Good	
14	Unattended Operation	☐ No		☐ Yes	
15	Maintenance Requirements	☐ High	☐ Medium	☐ Low	
16	Adverse Ambient Effects	☐ High	☐ Moderate	☐ Slight	
17	Submersion Proof	☐ No		☐ Yes	
18	Ruggedness	☐ Poor	☐ Fair	☐ Good	
19	Self Contained	☐ No		☐ Yes	
20	Precalibration	☐ No		☐ Yes	
21	Ease of Calibration	☐ Poor	☐ Fair	☐ Good	
22	Maintenance of Calibration	☐ Poor	☐ Fair	☐ Good	
23	Adaptability	☐ Poor	☐ Fair	☐ Good	
24	Cost	☐ High	☐ Medium	☐ Low	
25	Portability	☐ No		☐ Yes	

Comments:

SECTION VI

METHODS OF FLOW DETERMINATION

GENERAL

This section is intended to provide the reader with an overview of the physical principles that have been utilized in the design of equipment for the quantitative measurement of flows. It presents a discussion, in generic terms, that may help the reader to better follow the treatment of commercially available equipment given in Section VII. There are a number of excellent references on the subject and the reader is referred to them for a more in-depth presentation. Noteworthy among these are the ASME monograph on fluid meters (7) which was used as a guide for the organization of this section as well as much of its content, Replogle (8) and McMahon (9) which were also liberally used as resource material; the USDI Bureau of Reclamation's water measurement manual (10), the Leupold and Stevens water resources data book (11), and the many standard texts on hydraulics, fluid mechanics, etc.

Any flow measurement system can be considered to consist of two distinct parts, each of which has a separate function to perform. The first, or primary element, is that part of the system which is in contact with the fluid, resulting in some type of interaction. The secondary element is that part of the system which translates this interaction into the desired readout or recording. While there is almost an endless variety of secondary elements, primary elements are related to a more limited number of physical principles, being dependent upon some property of the fluid other than, or in addition to, its volume or mass such as kinetic energy, inertia, specific heat, or the like. Thus the primary elements, or rather their physical principles, form a natural classification system for flow measuring devices and are so used in this discussion.

Flow measurement systems may be thought of as belonging to one of two rather broad divisions, quantity and rate. In quantity meters, the primary element measures isolated (i.e., separately counted) quantities of fluid either in terms of mass or volume. Usually a container or cavity of known capacity is alternately filled and emptied, permitting an essentially continuous flow of the metered supply. The secondary element counts the number of these quantities and indicates or records them, often against time. In rate meters, by contrast, the fluid passes in a continuous, uninterrupted stream, which interacts with the primary element in a certain way, the interaction being dependent upon one or more physical properties of the fluid. In the secondary element, the quantity of flow per unit time is derived from this interaction by known physical laws supplemented by empirical relations. A general categorization of flow meters by division, classification, type, and sub-type is presented in Table 2. Each classification is discussed briefly in the following sub-sections.

A slightly modified form of the flow measurement equipment checklist given in Table 1 has been used to evaluate the various flow measuring devices and techniques in tabular form, and a matrix summary is given at the end of this section. It must be re-emphasized that these evaluations are made with a storm or combined sewer flow measurement application in mind and will not necessarily be applicable for other types of flows. They are necessarily somewhat subjective, and the writers apologize in advance to the clever reader who has made a particular device work satisfactorily in such an application and, hence, feels that it has been treated unfairly.

Only a few of the evaluation parameters normally have numbers associated with them. To assist the reader in interpreting the ratings, the following general guidelines were used. If the normal range of a particular device was considered to be less than about 10:1, it was termed poor; if it was considered to be greater than around 100:1, it was termed good. The intermediate ranges were termed fair. The accuracy that might reasonably by anticipated in measuring storm or combined sewer flows was considered rather than the best accuracy achievable by a particular device. For example, although a sharp-crested weir may be capable of achieving accuracies of ±1.5% or better in clear irrigation water flows, accuracies of much better than ±4-7% should not necessarily be anticipated for a sharp-crested weir measuring stormwater or combined sewer discharges. If the accuracy of a particular flow measuring device or method was considered to be better than around ±1-2%, it was termed good; if it was considered to be worse than around ±10%, it was termed poor. The intermediate accuracies were termed fair.

The flow measuring devices and techniques were not rated on two evaluation parameters, submersion proof and adaptability, because these factors are so dependent upon the design details of the secondary element selected by the user.

SITE SELECTION

The success or failure of selected flow measurement equipment or methods, with respect to accuracy and completeness of data collected as well as reasonableness of cost, depends very much on the care and effort execised in selecting the gaging site. Except for a few basic requirements which are applicable to all types of equipment and methods which will be discussed at this point, there are significant differences in site needs for various flow measurement devices. Particular site requirements will be addressed in the discussion of each equipment type.

A requirement which appears to be obvious, but which is frequently not sufficiently considered, is that the site selected be located to give the desired flow measurement. Does flow at the site provide information

TABLE 2. FLOW METER CATEGORIZATION

DIVISION	CLASSIFICATION	TYPE	SUBTYPE
QUANTITY	GRAVIMETRIC	WEIGHER	
QUANTITY	GRAVIMETRIC	TILTING TRAP	
QUANTITY	GRAVIMETRIC	WEIGH DUMP	
QUANTITY	VOLUMETRIC	METERING TANK	
QUANTITY	VOLUMETRIC	RECIPROCATING PISTON	
QUANTITY	VOLUMETRIC	OSCILLATING OR RING PISTON	
QUANTITY	VOLUMETRIC	NUTATING DISC	
QUANTITY	VOLUMETRIC	SLIDING VANE	
QUANTITY	VOLUMETRIC	ROTATING VANE	
QUANTITY	VOLUMETRIC	GEAR OR LOBED IMPELLER	
QUANTITY	VOLUMETRIC	DETHRIDGE WHEEL	
RATE	DIFFERENTIAL PRESSURE	VENTURI	
RATE	DIFFERENTIAL PRESSURE	DALL TUBE	
RATE	DIFFERENTIAL PRESSURE	FLOW NOZZLE	
RATE	DIFFERENTIAL PRESSURE	ROUNDED EDGE ORIFICE	
RATE	DIFFERENTIAL PRESSURE	SQUARE EDGE ORIFICE	CONCENTRIC
RATE	DIFFERENTIAL PRESSURE	SQUARE EDGE ORIFICE	ECCENTRIC
RATE	DIFFERENTIAL PRESSURE	SQUARE EDGE ORIFICE	SEGMENTED
RATE	DIFFERENTIAL PRESSURE	SQUARE EDGE ORIFICE	GATE OR VARIABLE AREA
RATE	DIFFERENTIAL PRESSURE	CENTRIFUGAL	ELBOW OR LONG RADIUS BEND
RATE	DIFFERENTIAL PRESSURE	CENTRIFUGAL	TURBINE SCROLL CASE
RATE	DIFFERENTIAL PRESSURE	CENTRIFUGAL	GUIDE VANE SPEED RING
RATE	DIFFERENTIAL PRESSURE	IMPACT TUBE	PITOT-STATIC
RATE	DIFFERENTIAL PRESSURE	IMPACT TUBE	PITOT VENTURI
RATE	DIFFERENTIAL PRESSURE	LINEAR RESISTANCE	PIPE SECTION
RATE	DIFFERENTIAL PRESSURE	LINEAR RESISTANCE	CAPILLARY TUBE
RATE	DIFFERENTIAL PRESSURE	LINEAR RESISTANCE	POROUS PLUG
RATE	VARIABLE AREA	GATE	
RATE	VARIABLE AREA	CONE AND FLOAT	
RATE	VARIABLE AREA	SLOTTED CYLINDER AND PISTON	
RATE	HEAD-AREA	WEIR	SHARP CRESTED
RATE	HEAD-AREA	WEIR	BROAD CRESTED
RATE	HEAD-AREA	FLUME	VENTURI
RATE	HEAD-AREA	FLUME	PARSHALL
RATE	HEAD-AREA	FLUME	PALMER-BOWLUS
RATE	HEAD-AREA	FLUME	DISKIN DEVICE
RATE	HEAD-AREA	FLUME	CUTTHROAT
RATE	HEAD-AREA	FLUME	SAN DIMAS
RATE	HEAD-AREA	FLUME	TRAPEZOIDAL
RATE	HEAD-AREA	FLUME	TYPE HS, H, AND HL
RATE	HEAD-AREA	OPEN FLOW NOZZLE	
RATE	FLOW VELOCITY	FLOAT	SIMPLE
RATE	FLOW VELOCITY	FLOAT	INTEGRATING
RATE	FLOW VELOCITY	TRACER	
RATE	FLOW VELOCITY	VORTEX	VORTEX-VELOCITY
RATE	FLOW VELOCITY	VORTEX	EDDY-SHEDDING
RATE	FLOW VELOCITY	TURBINE	
RATE	FLOW VELOCITY	ROTATING ELEMENT	HORIZONTAL AXIS
RATE	FLOW VELOCITY	ROTATING ELEMENT	VERTICAL AXIS
RATE	FORCE-DISPLACEMENT	VANE	
RATE	FORCE-DISPLACEMENT	HYDROMETRIC PENDULUM	
RATE	FORCE-DISPLACEMENT	TARGET	
RATE	FORCE-DISPLACEMENT	JET DEFLECTION	
RATE	FORCE-DISPLACEMENT	BALL AND TUBE	
RATE	FORCE-MOMENTUM	AXIAL FLOW MASS	
RATE	FORCE-MOMENTUM	RADIAL MASS	
RATE	FORCE-MOMENTUM	GYROSCOPIC	
RATE	FORCE-MOMENTUM	MANGUS EFFECT	
RATE	THERMAL	HOT TIP	
RATE	THERMAL	COLD TIP	
RATE	THERMAL	BOUNDARY LAYER	
RATE	OTHER	ELECTROMAGNETIC	
RATE	OTHER	ACOUSTIC	
RATE	OTHER	DOPPLER	
RATE	OTHER	OPTICAL	
RATE	OTHER	DILUTION	
RATE	OTHER	ELECTROSTATIC	
RATE	OTHER	NUCLEAR RESONANCE	

actually needed to fulfill project needs? Sometimes influent flows, diversions, or storage upstream or downstream from the selected site would bias the data in a manner not understood without a thorough study of the proposed site. Such study would include reference to surface maps and to sewerage maps and plans. Sometimes groundwater infiltration or unrecorded connections may exist. For these reasons, a thorough field investigation should be made before establishing a flow measurement site.

There are some situations where there is no choice of sites. Only a single site may be available where the desired flow measurement can be made. In this case, the problem is one of selecting the most suitable flow measurement equipment and methods for the available site.

A basic consideration in site selection is the possible availability of flow measurements or records collected by others. At times, data being collected by the U.S. Geological Survey, by the State, or by other public agencies can be used. There are locations where useful data, although not currently being collected, may have been collected in prior years. Additional data to supplement those earlier records may be more useful than new data collected at a different site. Other general site considerations include any history of surcharging, entry and backwater conditions, and intrusion from receiving waters.

Requirements which apply to all flow measurement sites are accessibility, personnel and equipment safety, and freedom from vandalism. If a car or other vehicle can be driven directly to the site at all times, the cost in time required for installation, operation, and maintenance of the equipment will be less, and it is possible that less expensive equipment can be selected. Consideration should be given to access during periods of adverse weather conditions and during periods of flood stage. Sites on bridges or at manholes where heavy traffic occurs should be avoided unless suitable protection for men and equipment is provided. If entry to sewers is required, the more shallow locations should be selected where possible. Manhole steps and other facilities for sewer access must be carefully inspected, and any needed repairs made. Possible danger from harmful gases, chemicals, or explosion should be investigated. With respect to sites at or near streams, historical flood marks should be determined and used for placement of access facilities and measurement equipment above flood level where this is possible. Areas of known frequent vandalism should be avoided.

Selection of sites in open, rather than secluded, areas may help to reduce vandalism. Often, the only solution to prevent destruction of facilities is to place them in solid concrete or steel shelters, and to surround them with heavy fencing. Erection of warning signs is futile, as they often serve only to provide targets.

In development of a system or network of flow measurement stations, primary consideration must be given to cost if the maximum benefit is to result from available funds. Therefore, cost must be considered in selection of each gaging site. Cost reduction can result from selection of sites where the less expensive types of equipment, which will fulfill project requirements of accuracy and completeness, can be installed. For example, if a site is selected where conditions are such that satisfactory records can be obtained with a weir installation, this would be preferable to selecting a site where the head loss required by a weir would not be available, and the expense of installing a Parshall flume must be met.

GRAVIMETRIC

As indicated in Table 2, gravimetric meters include weighers, tilting trap and weigh dump meters. Weighing the fluid is a primary standard and, since the accuracy of weighing devices is routinely considered to be better than ±0.1%, they are frequently used to calibrate other meters as, for example, at the new National Bureau of Standards flowmeter calibration facility. In its simplest form, a gravimetric meter involves determining the weight of a quantity of fluid in a tank mounted on beam scales, load cells, or some other mass or force measuring device. Where flow is uniform, an indication of flow rate can be obtained by measuring the time over which the measured weight of fluid is gathered. The tipping bucket rain gage is probably one of the most common meters of this type in field use. Another field application, used where a scale or some other weighing device is available, is the simple "bucket and stopwatch" technique. Practical considerations limit the use of this technique to fairly low flow rates, however. Gravimetric meters may often have a useful range of up to 100:1, and accuracies of ±1% of the reading or better are routine.

All types of gravimetric meters as a class are evaluated in Table 3. Since they are generally not well suited for storm or combined sewer flow measurement, no further discussion will be given.

VOLUMETRIC

Whenever the fluid density can be assumed to be reasonably constant, a volumetric measure of flow is adequate. Because of their simplicity and lower cost as compared to gravimetric meters, most quantity meters found on the market today are volumetric devices. A representative, but not inclusive, listing of types of volumetric meters is given in Table 2. As with gravimetric devices, rates of flow can be indicated with many volumetric meters by using appropriate secondary elements.

Probably the most elementary type of volumetric device is the metering tank. An open tank is repeatedly filled to a fixed depth and emptied.

TABLE 3. GRAVIMETRIC METER EVALUATION (ALL TYPES)

Evaluation Parameter		Scale		
1	Range	☐ Poor	☐ Fair	☒ Good
2	Accuracy	☐ Poor	☐ Fair	☒ Good
3	Flow Effects on Accuracy	☒ High	☐ Moderate	☐ Slight
4	Gravity & Pressurized Flow Operation	☐ No		☒ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☒ High	☐ Moderate	☐ Slight
7	Flow Obstruction	☒ High	☐ Moderate	☐ Slight
8	Head Loss	☒ High	☐ Medium	☐ Low
9	Manhole Operation	☒ Poor	☐ Fair	☐ Good
10	Power Requirements	☐ High	☒ Medium	☐ Low
11	Site Requirements	☒ High	☐ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☒ High	☐ Moderate	☐ Slight
13	Simplicity and Reliability	☒ Poor	☐ Fair	☐ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☒ High	☐ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☒ Fair	☐ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☒ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☒ High	☐ Medium	☐ Low
25	Portability	☒ No		☐ Yes

Although potentially not as accurate as weighing, since both the fluid and tank are subject to temperature effects, accuracies of about ±1% of reading are routinely achieved. The usable range of a metering tank device is a function of its design, but 10:1 is commonly achieved.

There have been a few instances where existing structures have been used as volumetric flow measuring devices for stormwater or combined sewage. For example, in at least one location wet wells have been utilized in a "fill and draw" fashion in order to provide an indication of flow. The monitoring of pump operations at lift stations in general has been used in a number of cases to obtain flow information. Such techniques rely upon the use of existing equipment and structures, however, and flow measurement was not their original purpose. For this reason, they must be considered as techniques of opportunity rather than as candidates for flow measurement equipment per se; consequently, they will not be included in the evaluation table.

Many of the flow measuring devices in the volumetric classification are positive displacement meters. Such units may be considered to be fluid motors operating with a very high volumetric efficiency under a very light load. This load is made up of two parts; the internal load due to friction within the primary element, and the external load imposed by the secondary element or register. As in all fluid motors, work done against a load results in a pressure drop. The main factors influencing the magnitude of this pressure drop are the type of seal required, the power required to drive the register, the viscosity of the liquid, and the rate of flow.

Various ingenious mechanical implementations of such meters include such types as the reciprocating piston, oscillating or ring piston, nutating disc, sliding and rotating vane, and gear or lobed impeller. Several of these have seen application in water meter designs for residential and commercial use. They are seldom found in large sizes and are obviously poorly suited for measuring storm or combined sewer flows. A special adaptation of a vane type meter is the Dethridge Wheel. These devices are widely used in Australia and New Zealand to measure irrigation water flows, but are almost unknown in the United States. Accuracies of ±3.5% are reported for free discharge conditions for discharge rates between 0.042 and 0.14 cm/s (1.5 and 5.0 cfs). Maximum ranges of 5:1 have been achieved in smaller sizes.

All types of volumetric meters as a class are evaluated in Table 4. Since they are generally not well suited for storm or combined sewer flow measurement, no further discussion will be given. Complete descriptions and discussions can be found in the references - especially ASME (7), Replogle (8), and McMahon (9).

TABLE 4. VOLUMETRIC METER EVALUATION (ALL TYPES)

Evaluation Parameter		Scale		
1	Range	☒ Poor	☐ Fair	☐ Good
2	Accuracy	☐ Poor	☐ Fair	☒ Good
3	Flow Effects on Accuracy	☒ High	☐ Moderate	☐ Slight
4	Gravity & Pressurized Flow Operation	☐ No		☒ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☒ High	☐ Moderate	☐ Slight
7	Flow Obstruction	☒ High	☐ Moderate	☐ Slight
8	Head Loss	☐ High	☒ Medium	☐ Low
9	Manhole Operation	☒ Poor	☐ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☒ High	☐ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☒ High	☐ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☒ Fair	☐ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☒ High	☐ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☒ Fair	☐ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☒ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☒ High	☐ Medium	☐ Low
25	Portability	☒ No		☐ Yes

DIFFERENTIAL PRESSURE

Flow measuring devices that fall in the differential pressure classification operate by converting energy from one form to another. For example, in those primary devices that have a reduced cross-section, potential energy is converted into kinetic energy to produce a differential pressure, while in the impact type devices the reverse is true. Centrifugal type devices utilize the acceleration of the flow around a bend, while linear resistance type devices are based on frictional losses. In many designs a combination of velocity head, frictional losses, or stream-line bending is employed. An important feature of all flow measuring devices in the differential pressure classification used here is that they can only be used in a closed conduit flowing full and under pressure.

Venturi

As noted above, when a fluid flows through a conduit of varying cross-section its velocity varies from point to point along the conduit or passage. If the velocity increases, the passage is called a nozzle, and the kinetic energy increases at the expense of internal energy. If the velocity decreases, the passage is called a diffuser, and the internal energy increases at the expense of kinetic energy. If the cross-section of a nozzle decreases continuously from entrance to exit it is called converging, and if it increases continuously it is called diverging. The cross-section of a diffuser may either increase or decrease depending on whether the flow is supersonic or subsonic. A venturi is a converging nozzle followed by a subsonic diffuser. The region of minimum cross-section is called the throat. A number of different venturi geometries have been developed over the years, one of the more common being the standard (long-type) Herschel Venturi meter tube (Figure 3).

The venturi meter is one of the most accurate devices for measuring liquid flow rates in pipes, but it is not in common use for waste flow measurement for a number of reasons, not the least of which is its cost. The venturi causes a very low pressure loss and, with proper precautions, is good for use in liquids with high solids concentrations. For example, ASTM Standard D 2458 states (12) "*When a venturi tube is to be used for metering liquids containing large concentrations of suspended solids or sludge, the annular ring is eliminated and replaced by single hole taps at the inlet and throat and these are flushed continuously with clean water.*" It is further recommended that the flushing water pressure should exceed the maximum line pressure by at least 0.7 kgf/sq cm (10 psi). The flushing water flows should be equal and continuous, and held to a small quantity to prevent any measurable pressure differential which would be reflected in the metering instrument.

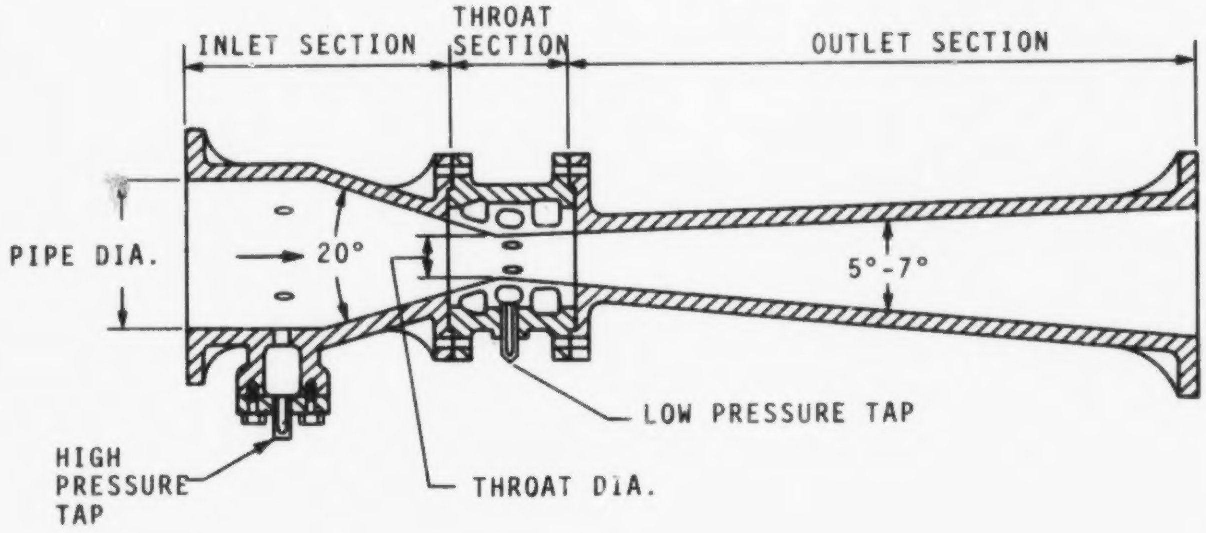

INLET SECTION
THROAT SECTION
OUTLET SECTION
PIPE DIA.
20°
5°-7°
LOW PRESSURE TAP
HIGH PRESSURE TAP
THROAT DIA.

Figure 3. Herschel Standard (Long) Venturi Meter Tube

It is essential that the flow entering a venturi tube be of uniform turbulence, free from helical flow and from high or low pressure areas. Therefore, long uninterrupted runs of straight pipe upstream from the venturi location are desirable for accurate fluid metering. Straightening vanes can often be used to reduce the upstream straight pipe run requirement when the disturbing device produces spiral flows, but they do little to reduce the effects of elbows and partly opened gate valves. The required run depends upon the nature of the upstream element; e.g., elbow, gate and globe valve, decreaser, increaser, etc., and the ratio of the throat diameter to the pipe diameter. Typically, the minimum desirable straight run will be from 5 to 20 pipe diameters. Conditions downstream from the venturi tube have little effect on its performance.

The pressure differential of a venturi tube can be measured using mercury columns, electrically, pneumatically, or by incorporating a water level sensing device (e.g., a float operated instrument) and water columns. Although manufacturers typically supply rating curves with their instruments, ASTM (12) recommends that each venturi be calibrated in place to meet accuracy standards. Accuracy is affected by changes in density, temperature, pressure, viscosity, and by pulsating flow. Under ideal conditions a venturi can yield accuracies of around ±0.5% of the reading, but more typical accuracies achieved are about ±1 or 2%. Most installations are usable over a range of 5:1 or so. Venturi tube meters are evaluated in Table 5.

Flow Tubes

Following the development of the Herschel venturi tube in 1887, a number of variations such as the short-coned venturi were developed. Among the more recently introduced venturi-type primary devices is the Dall flow tube (13), which was developed in England. The Dall tube consists of a flanged cylindrical body designed with a short straight inlet section which terminates abruptly with a decrease in diameter, thus forming a shoulder. This is followed by a conical reducer and diverging outlet separated by a narrow throat. In effect, the Dall tube uses stream-line bending as well as velocity head to obtain a differential pressure larger than that produced by a standard venturi meter. Single hole pressure taps are located at the inlet shoulder and the throat (Figure 4). Both pressure taps can be continuously flushed with clean water to prevent plugging from solids in the flow as done with the venturi tube.

The Dall tube is almost as accurate as the standard venturi and has a higher head recovery, being one of the lowest permanent head loss devices known. It is more sensitive to system disturbances than the venturi, and straight upstream pipe runs of 40 pipe diameters or more may be required. Although somewhat cheaper than the venturi, the Dall tube must still be considered expensive. It is much shorter than either

TABLE 5. VENTURI TUBE METER EVALUATION

Evaluation Parameter		Scale		
1	Range	☒ Poor	☐ Fair	☐ Good
2	Accuracy	☐ Poor	☐ Fair	☒ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☐ Moderate	☒ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☒ Poor	☐ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☒ High	☐ Moderat	☐ Slight
12	Installation Restrictions or Limitations	☒ High	☐ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☒ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☒ High	☐ Medium	☐ Low
25	Portability	☒ No		☐ Yes

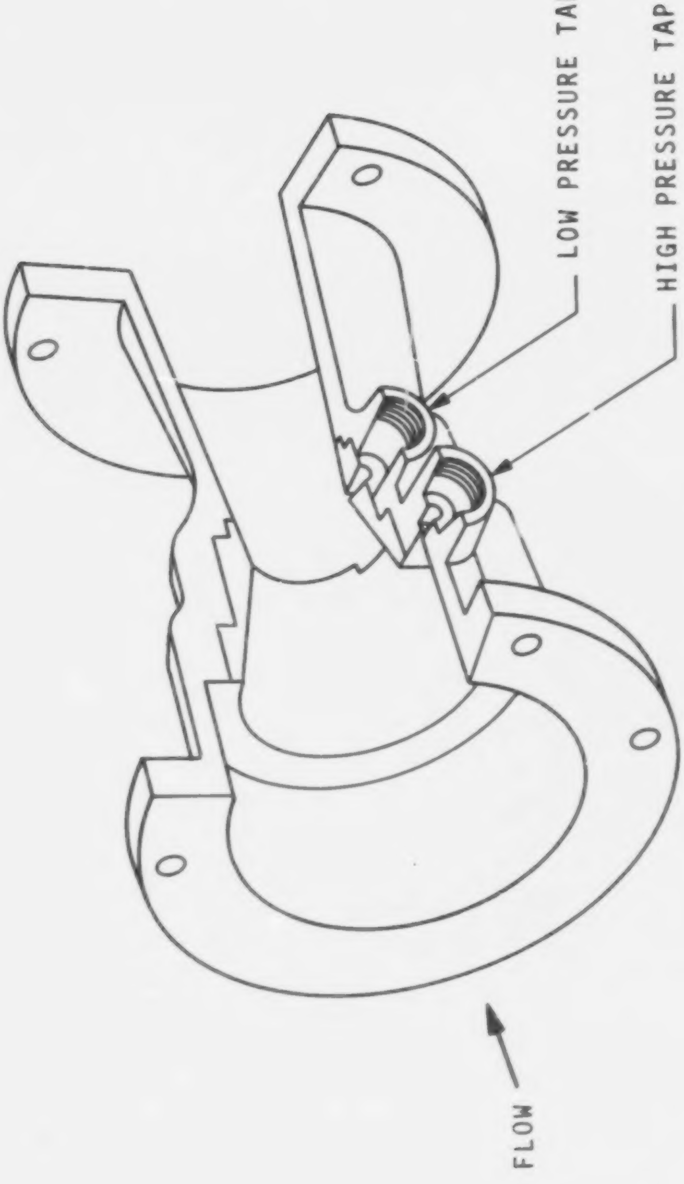

LOW PRESSURE TAP
HIGH PRESSURE TAP
FLOW

Figure 4. Dall Flow Tube

long or short venturi tubes, and thus has less of an installation restriction. The throat of the Dall tube can foul, and it is not generally recommended for extremely dirty fluids. Dall tubes are evaluated in Table 6.

There have also been a number of recent American proprietary developments, typical of which is the "Lo-Loss" tube. It senses the vacuum at the throat produced by the centrifugal action of the liquid rounding a curve and the impact pressure at the inlet. It is also a high head recovery device but, unlike the Dall tube, can generally be successfully used to meter dirty fluids. With this exception, the evaluation comments of Table 6 can be assumed applicable to the "Lo-Loss" tube also.

The Gentile tube is a somewhat different venturi-type differential pressure producer, in which there is a slight constriction in the line. Pressure ports exist in the wall of the constriction. These ports face in opposite directions and the effect is somewhat similar to the multiple-port Pitot tube. In effect these Pitot tubes are used to amplify the throat pressure. Because of the type of construction and size of the ports, the device has limitations for the measurement of flow of liquids which carry solid matter in suspension. It also suffers from an extremely limited range (less than half that of a Dall tube), a greater sensitivity to upstream disturbances, and less head recovery; consequently, this device will not be discussed further.

Flow Nozzle

Various designs have been developed for flow nozzles, resulting in characteristics that approach those of a venturi tube in one extreme (venturi insert nozzle) and those of an orifice meter in the other (ASME long radius nozzle). More typically, a flow nozzle has an entrance cone and throat, as in a venturi tube, but lacks the recovery cone (diffuser). This omission essentially affects the head recovery only. A major difference (and advantage over the venturi tube) in installation is that a flow nozzle can be installed in pipe flanges (see Figure 5). Nozzles are less expensive than venturi tubes, but cost more than orifice meters. In general they are more sensitive to upstream disturbances and 20 or more pipe diameters of straight run upstream of the flow nozzle are required for successful operation. While some designs, (e.g., ASME nozzle) are quite well suited (with proper precautions) for measuring liquids high in suspended solids, other (e.g., venturi insert nozzle) are not recommended for use in such flows, due to some aspect of their particular design that would tend to promote plugging or clogging. Flow nozzle accuracies can approach those of venturi tubes, especially when calibrated in place. It is also possible to use a flow nozzle in cases where a pipe (flowing full) discharges freely to the atmosphere. In such cases only the high pressure tap is needed; see Figure 6. Flow nozzles as a group are evaluated in Table 7.

TABLE 6. DALL TUBE METER EVALUATION

	Evaluation Parameter	Scale		
1	Range	☒ Poor	☐ Fair	☐ Good
2	Accuracy	☐ Poor	☐ Fair	☒ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☒ Moderate	☐ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☒ Poor	☐ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☒ High	☐ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☒ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☒ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☒ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☒ High	☐ Medium	☐ Low
25	Portability	☒ No		☐ Yes

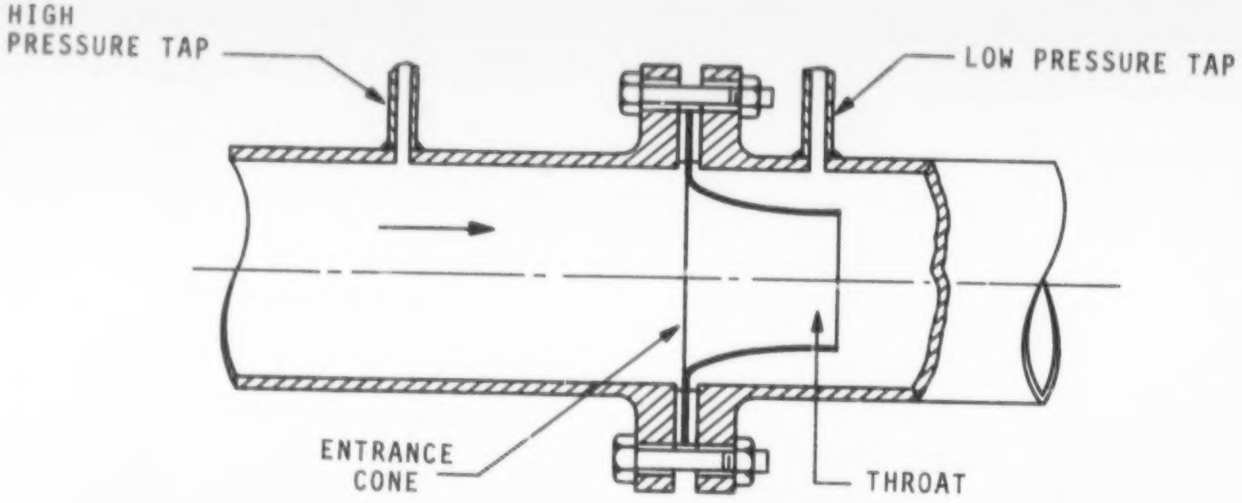

HIGH
PRESSURE TAP
LOW PRESSURE TAP
ENTRANCE
CONE
THROAT

Figure 5. Typical Flow Nozzle Installation

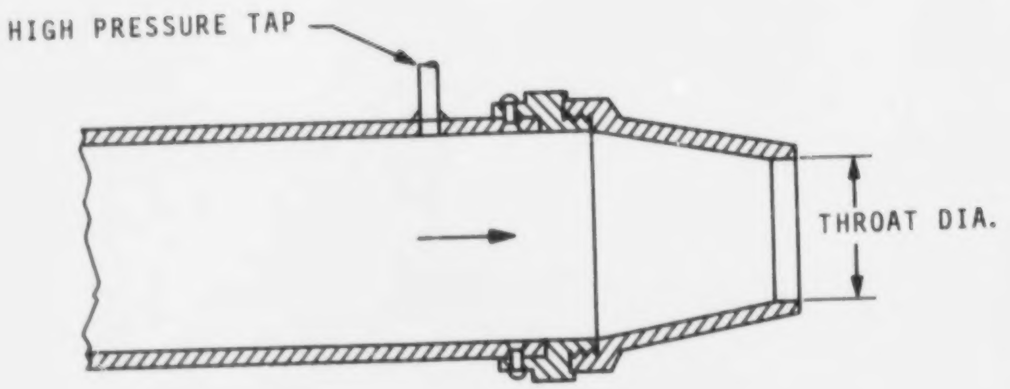

HIGH PRESSURE TAP
THROAT DIA.

Figure 6. Flow Nozzle Discharging to Atmosphere

TABLE 7. FLOW NOZZLE METER EVALUATION

Evaluation Parameter		Scale		
1	Range	☒ Poor	☐ Fair	☐ Good
2	Accuracy	☐ Poor	☐ Fair	☒ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☐ Moderate	☒ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☒ Medium	☐ Low
9	Manhole Operation	☒ Poor	☐ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☒ High	☐ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☒ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☐ Medium	☒ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☒ Medium	☐ Low
25	Portability	☒ No		☐ Yes

Orifice Meters

The orifice meter is one of the oldest flow measuring devices in existence. Its differential pressure is due to a combination of velocity head, frictional losses, and stream-line bending (acceleration). The relative contribution is determined by whether pipe taps, vena contracta taps, or flange taps are used. The thin plate orifice meter is the most commonly used flow measuring device in pipes. The orifice is a round hole in a thin flat plate that is clamped between a pair of flanges at a point in the pipe. Although some designs have a rounded edge facing into the direction of the flow and perhaps a short tube with the same inside diameter as the orifice diameter extending downstream, it is more common to use a sharp 90-degree corner on the upstream edge. The pressure taps are located upstream and downstream of the orifice plate. An orifice plate can also be used at the end of a pipe flowing full and discharging to atmosphere, in which case only a single pressure tap is required.

Orifice meters work well with clean fluids but are not applicable, except in a limited sense, to flows high in suspended solids due to the tendency of solids to accumulate upstream of the orifice plate and thereby change its calibration. There are two designs that will accommodate limited amounts of suspended solids. The eccentric orifice plate has a hole which is bored off-center, usually tangent to the bottom of the flow line. The segmental orifice plate has a segment removed from the lower half of the orifice plate. In addition, there are many special-purpose devices that are really combinations of flow nozzles and orifice plates. These have arisen due to requirements to minimize viscosity effects in heavy fluids, etc.

Orifice plates are the most sensitive of all the differential pressure devices to effects of upstream disturbances, and it is not uncommon to need 40 to 60 pipe diameters of straight run upstream of the installation. Orifice plates also produce the greatest head loss as can be seen by the comparison curves of Figure 7. Orifice meters can be quite accurate, with ±0.5% or better achievable when calibrated in place. They are lowest in cost of all the differential pressure producers. Because of nonlinear flow effects, their usable range is small (on the order of 5:1) unless rated in place. Orifice meters are evaluated as a group in Table 8.

Centrifugal Meters

Flow acceleration induced in a fluid going around a bend (such as an elbow) produces a differential pressure that can be used to indicate flow. The pressure on the outside of an elbow is greater than on the inside, and pressure taps located mid-way around the bend (i.e., 45 degrees from either flange) can be connected to a suitable secondary

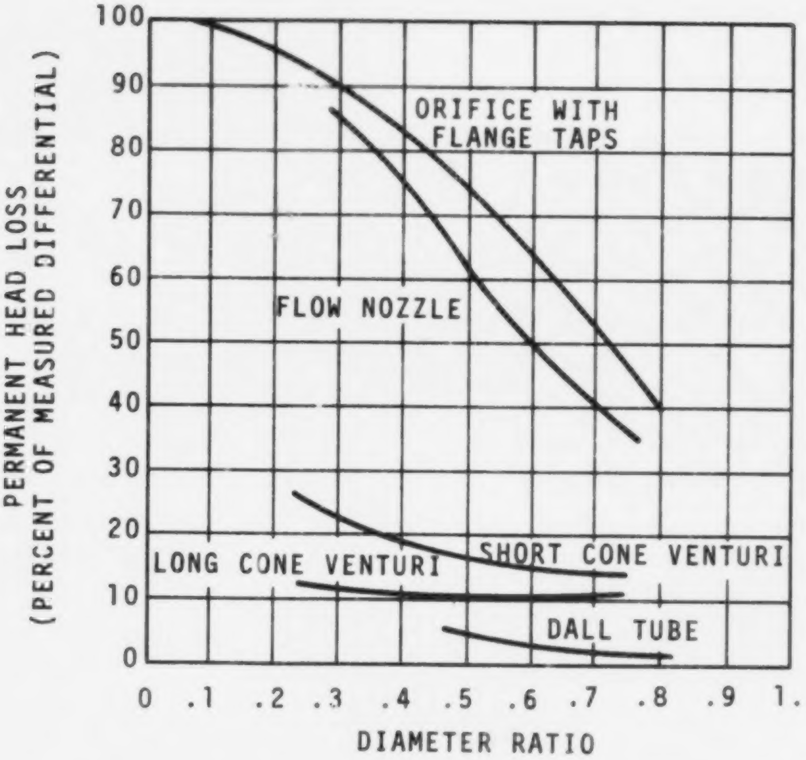


Figure 7. Head Loss of Differential Pressure Meters

TABLE 8. ORIFICE METER EVALUATION

	Evaluation Parameter	Scale		
1	Range	☒ Poor	☐ Fair	☐ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☒ High	☐ Moderate	☐ Slight
7	Flow Obstruction	☒ High	☐ Moderate	☐ Slight
8	Head Loss	☒ High	☐ Medium	☐ Low
9	Manhole Operation	☒ Poor	☐ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☒ High	☐ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☒ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☒ High	☐ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☒ Fair	☐ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☒ Poor	☐ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☐ Medium	☒ Low
25	Portability.	☐ No		☒ Yes

element for indicating or recording. Cortelyou (14), Taylor and McPherson (15), and Replogle, et. al. (16) provide fuller discussions of centrifugal meters. The turbine scroll case and guide vane speed ring do not appear at all well suited for storm or combined sewer applications, and so will not be discussed.

The elbow meter may have some application in existing pipe systems. It should not be considered as a candidate for accurate flow measurement in new construction, however. It is inexpensive, offers no additional head loss, can tolerate solids if the pressure taps are flushed (see venturi discussion), and is not especially subject to calibration shifts. If calibrated in place, accuracies of about ±1 or 2% (or better in some cases) may be achieved. More typically, accuracies of 3 to 10% are encountered. Unless calibrated in place, straight pipe runs of at least 20 pipe diameters should be provided both upstream and downstream of the elbow. The usual rangeability is around 3:1. Elbow meters are evaluated in Table 9.

Impact Tube

In the impact tube, kinetic energy (due to fluid velocity) is converted into potential energy (stagnation pressure) and the differential pressure (as compared with static pressure in the pipe) is related to flow velocity at the point of measurement. Figure 8 depicts the two essential ingredients and a particular construction known as the Prandtl-Pitot tube. Alternate designs consist of essentially the same two basic ingredients (impact tube and pressure tube) and differ only in the details of their construction. H. Pitot's original design (1732) had two tubes, one of which was bent through 90 degrees at its lower end and positioned facing into the flow. H. Darcy's design (1852) had each tube bent through 90 degrees, with one facing upstream (impact) and the other facing downstream. In addition to the Prantdl design (with its hemispherical head) which is popular today, especially in Europe, is the Brabbe design with a conical head, which is popular in the United States and United Kingdom. In another design, two parallel small-diameter tubes are beveled at their open ends, one pointing upstream (impact) and one pointing downstream (static).

It must be emphasized that impact tubes measure point velocity only. Flow is calculated by multiplying the mean velocity of the fluid by the area of the pipe cross-section. For pipes flowing full and under pressure it has been determined that the mean velocity of flow is about 83% of the velocity in the center of the pipe and it occurs at a point approximately one-fourth the radius from the wall to the center. Velocity close to the pipe wall is only about one-half the velocity at the center. To avoid upset of such normal velocity distributions it is necessary to have a straight pipe run of some 15 to 50 pipe diameters in length upstream of the measuring point. Alternately, velocity traverses

TABLE 9. ELBOW METER EVALUATION

	Evaluation Parameter	Scale		
1	Range	☒ Poor	☐ Fair	☐ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☐ Moderate	☒ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☒ Poor	☐ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☒ High	☐ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☒ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☐ Medium	☒ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☒ No		☐ Yes
21	Ease of Calibration	☐ Poor	☒ Fair	☐ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☐ Medium	☒ Low
25	Portability	☒ No		☐ Yes

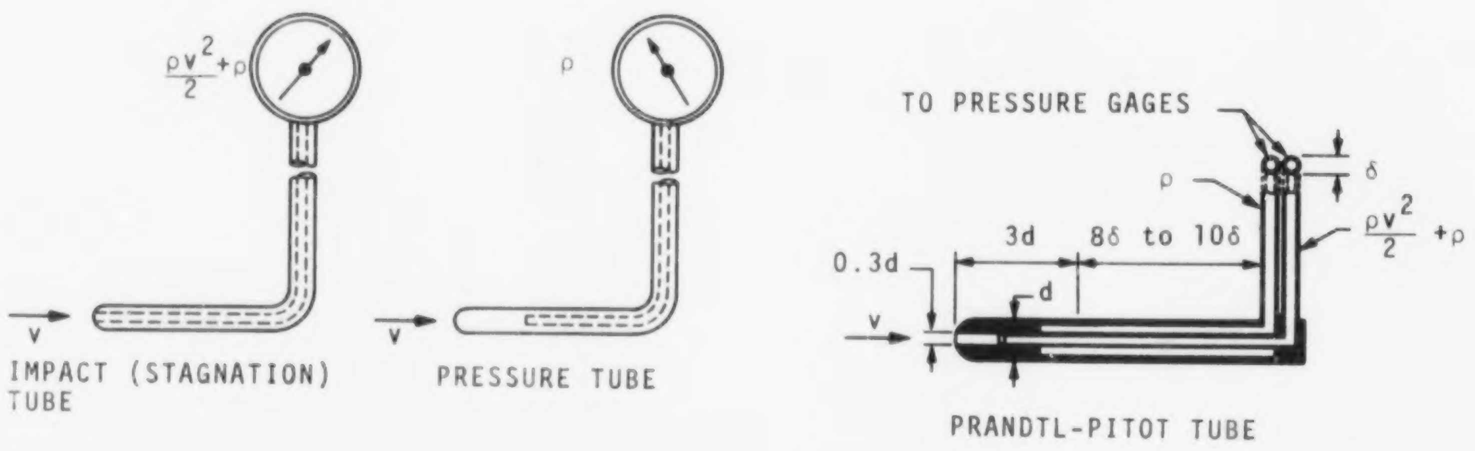

$\frac{\rho v^2}{2} + \rho$
v
IMPACT (STAGNATION) TUBE
ρ
v
PRESSURE TUBE
TO PRESSURE GAGES
δ
ρ
3d
8δ to 10δ
$\frac{\rho v^2}{2} + \rho$
0.3d
d
v
PRANDTL-PITOT TUBE

Figure 8. Prandtl-Pitot Impact Tube

can be run to determine the point of mean velocity. Such an approach also allows the pitot tube to be used in conduits of noncircular cross-section and under open channel flow conditions.

With very high velocities dynamic instability may occur, and erroneous readings result from the tube vibrations. However, the chief disadvantage of most pitot tube designs is that rather sophisticated secondary devices are required to accurately determine the pressure differential which may be quite small at low velocities, e.g., less than 0.3 m/s (1 fps). This makes continuous flushing secondary devices more difficult to employ and, to the writers' knowledge, no such attempt has yet been made.

Therefore, impact tube type devices are generally not satisfactory for measuring wastes containing appreciable quantities of suspended solids because of the possibility of plugging of the small openings in the tubes. In view of this, the vulnerability to damage arising from their intrusive nature, and the difficulties in applying them in open channel flows of varying depths, no further discussion will be given.

Linear Resistance

Linear resistance meters use friction losses to create a differential pressure that can be related to flow rate. The resistance of a long pipe section may be used, but one or more fine tubes in parallel (capillary tube) or a section of pipe packed with steel wool, granular materials, or the like (porous plug) are more typical. Fleming and Binder (17), Greef and Hackman (18), and Sovers and Binder (19) discuss various approaches and designs. Accuracies to 1% of the reading and ranges of 10:1 may be achieved. There is no pressure recovery. Because of the impracticality of utilizing such devices for measuring storm or combined sewer flows, they will not be discussed further.

VARIABLE AREA

Whereas differential pressure flow measuring devices are characterized by the invariability of the area ratio, in variable area meters the magnitude of the varying cross-sectional area is the measure of the rate of flow. A differential pressure does exist, but it is relatively constant. Variable area flowmeters may be divided into two main groups, valve type (e.g., hinged or sliding gate) and float type (e.g., cone-and-float). Variable area devices were invented by E. A. Chameroy, who patented an instrument constituting a prototype of the rotameter in 1868, and G. F. Deacon, who was given a patent for a cone-and-disc flowmeter in 1875. Sir J. A. Ewing was the first to apply a tapered glass tube in a liquid rotameter in 1876, and in 1910 K. Kupper introduced inclined slots on the upper rim of the float and first used the term rotameter for this type of device, because of the rotary motion of the float. Discussions of such devices are given by Kehat (20) and Gilmont and Roccanova (21). Accuracies to ±1% of full scale and ranges to 10:1 may be achieved. However, to maintain accuracy in a rotameter it is absolutely essential that both the tube and the float be kept clean. Thus, a storm or combined sewer application would be inappropriate and, consequently, they will not be discussed further.

HEAD - AREA

Flow measurement devices in this classification are characterized by a simultaneous variation of both flow cross-sectional area and head. These parameters do not vary indpendently, however, and it is the function of the primary device to produce a flow that is characterized by a known relationship (usually nonlinear) between a liquid level measurement (head) at some location and the overall discharge. This relationship or head-discharge curve is called the rating for the particular structure or device. Since these devices implicitly require a free surface, they are only suitable for open channel flows.

The change in elevation of the free surface is measured by the secondary device which may also convert stage to discharge automatically. Stilling wells are often used, being connected by suitable taps to the location in the primary device where knowledge of the flow depth is desired. The secondary device then monitors the relatively stable surface level of the fluid in the stilling well. To avoid the necessity of frequent cleaning of the stilling well and to help prevent plugging of the tap, fresh water is frequently trickled into the well at a rate sufficient to ensure that sewage isn't likely to enter. An overpressure of at least 0.003 meter (0.01 ft) is usually required to keep the well and tap clear, but in some cases greater cleaning flows along with frequent flushing will be necessary.

Slope-Area Method

In this technique, the flow conduit itself serves as the primary device. Historically, it has been used to obtain instantaneous discharges rather than continuous records. Some discharge relationship such as the Manning formula is used to relate depth to flow rate. For best results, a straight course of channel of at least 61 meters (200 ft) and preferably up to 305 meters (1000 ft) in length is required. It should be nearly uniform in slope, cross-section, and roughness and free of rapids, abrupt falls (dips), sudden contractions or expansions, and tributary inflows.

The Manning formula requires knowledge of the channel cross-section and liquid depth so that the flow cross-section and hydraulic radius can be calculated. It also requires knowledge of the slope of the water surface (not the conduit invert). This slope may be determined by dividing the difference in the water surface elevations at the two ends of the course, as determined by secondary devices carefully referenced to a common datum level, by the length of the course. Also required in the Manning formula is a roughness factor which depends upon the character of the conduit lining and the depth of flow (i.e., it is not constant for a given channel). Because the proper selection of the roughness factor is at best an estimate, the discharge determined by the slope-area method is only an approximation, and it should be used only where accuracy requirements are low.

All too often, the slope-area method is applied by measuring the flow depth at a single point and using the slope of the conduit invert in the Manning formula. For nonuniform or unsteady flow, the water surface slope will be changing and will certainly not be equal to the channel slope. The Manning formula was not intended for use under such conditions. It is preferable to perform calibration in place and develop an empirical rating curve for each measuring site. The slope-area method is evaluated in Table 10.

Weirs

A weir is essentially an overflow structure or dam built across the flow conduit to measure the rate of flow. For a weir of a given size and shape with free-flow, steady-state conditions and proper weir-to-pool relationships, only one depth of liquid can exist in the upstream pool for a given discharge. Discharge rates are computed by measuring the vertical distance from the crest of the overflow part of the weir to the water surface in the pool upstream of the crest and referring to the rating curve for the particular weir or class of weirs at hand. Thus, a weir may be thought of as a device for shaping the flow of the liquid in a definite way such as to allow a single depth reading to be uniquely related to a discharge rate. Weirs may be further categorized as being either sharp-crested or broad-crested; each will be discussed in turn.

Sharp-Crested Weirs - When the top edge of the weir is thin or beveled with a sharp upstream corner (similar to a thin plate orifice) so that the water does not contact any part of the weir structure downstream but, rather, springs past it, the weir is called a sharp-crested weir. Figure 9 depicts some common weir terms and their relationships. As noted, the minimum height of the weir crest should be at least two, and preferably three, times the maximum head expected over the weir. The contraction of the nappe (overfalling stream) after springing clear of the sharp crest is termed crest contraction. If the bottom of the approach channel is not far enough below the crest of the weir, the crest contraction is partially suppressed, and standard weir tables cannot be used. The slight drop in the liquid surface which begins upstream from the weir a distance of at least twice the head on the crest is called

TABLE 10. SLOPE-AREA METHOD EVALUATION

Evaluation Parameter		Scale		
1	Range	☐ Poor	☒ Fair	☐ Good
2	Accuracy	☒ Poor	☐ Fair	☐ Good
3	Flow Effects on Accuracy	☒ High	☐ Moderate	☐ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☒ High	☐ Moderate	☐ Low
6	Effect of Solids Movement	☐ High	☐ Moderate	☒ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☐ Fair	☒ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☒ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☒ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☐ Medium	☒ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☒ No		☐ Yes
21	Ease of Calibration	☐ Poor	☒ Fair	☐ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☒ High	☐ Medium	☐ Low
25	Portability	☒ No		☐ Yes

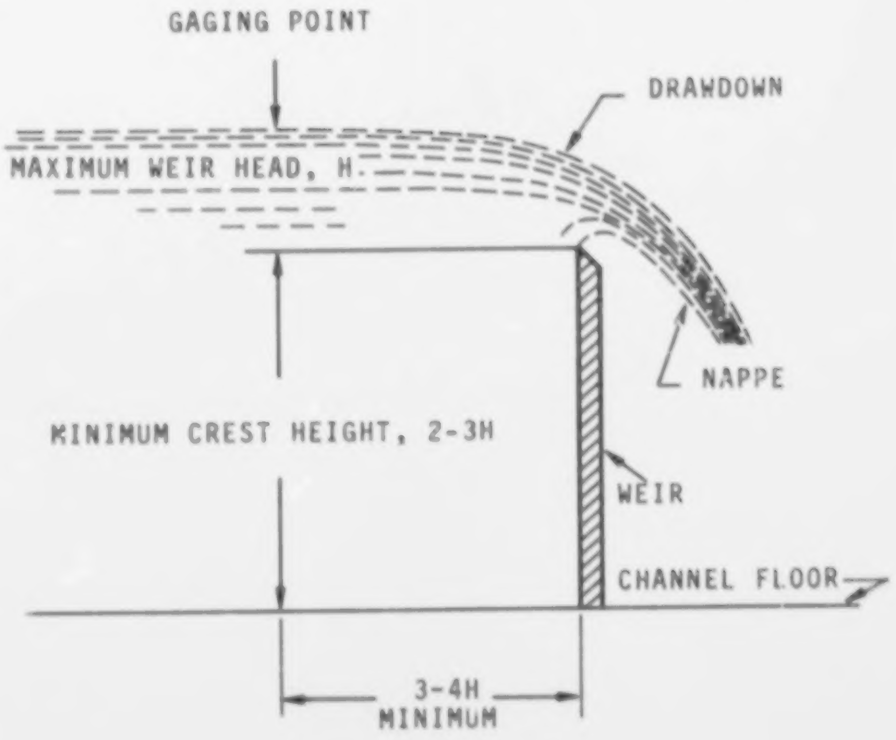

GAGING POINT
DRAWDOWN
MAXIMUM WEIR HEAD, H.
NAPPE
MINIMUM CREST HEIGHT, 2-3H
WEIR
CHANNEL FLOOR
3-4H
MINIMUM

Figure 9. Weir Terms and Their Relationships

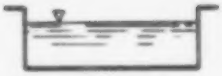
surface contraction or drawdown. To avoid sensing the effects of drawdown, the gaging point should be located upstream of the weir crest a distance of at least three, and preferably four, times the maximum head expected over the weir.

When the water level in the downstream channel is sufficiently below the crest to allow free access to the area beneath the nappe, say at least 15 cm (6 in.), the flow is said to be free (critical). When the water level under the nappe rises above the crest elevation, the flow may be considered submerged. This may or may not affect the discharge, and there is some question whether dependable measurements can be expected in this range. As the water level downstream rises appreciably over half of the head on the crest, the degree of submergence will appreciably affect the rate of flow. To determine the rate of flow under such submerged (sub-critical) conditions, both the upstream and downstream heads must be measured and reference made to submerged flow tables. A very good treatment of submerged weirs is given by Skogerboe, et al (22).

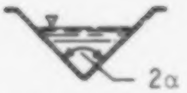
Many different geometries have been used for the notch in the weir plate that shapes the nappe and thereby allows the rating curve to be developed. Some sharp-crested weir profiles are depicted in Figure 10.

Rectangular Weirs - One of the oldest and most common is the rectangular weir, which is used in one of two configurations. When the distances from the sides of the weir notch to the sides of the channel (weir pool) are great enough (at least two or three times the head on the crest) to allow the liquid a free, unconstrained lateral approach to the crest, the liquid will flow uniformly and relatively slowly toward the weir sides. As the flow nears the notch it accelerates, and as it turns to pass through the opening, it springs free laterally with a resulting contraction that results in a jet narrower than the weir opening. Under such conditions the weir is called a contracted weir. If a rectangular weir is placed in a channel whose sides also act as the sides of the weir, there can be no lateral contractions and the weir is called a suppressed weir. Special care must be taken with these weirs to assure proper aeration beneath the nappe. This is usually accomplished by placing vents on both sides of the weir box under the nappe.

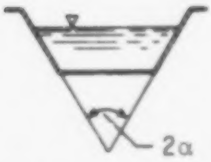
V-Notch Weirs - The triangular or V-notch sharp-crested weir was developed to allow accurate measurement of small flows. The angle (2α) most commonly used is 90 degrees. Because a V-notch weir has no crest length, the head required for a small flow through it is greater than that required for other common types of weirs. This is an advantage for small discharges in that the nappe will spring free of the crest, whereas it might cling to the crest of another type of profile and make the measurement worthless. The V-notch weir is the best profile for measuring discharges less than 28 ℓ/s (1 cfs) and is as accurate as any



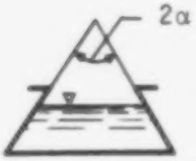
RECTANGULAR



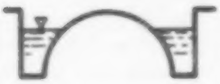
TRIANGULAR OR V-NOTCH



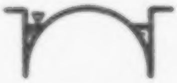
TRAPEZOIDAL (INCLUDING CIPOLLETTI)



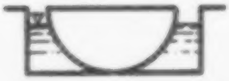
INVERTED TRAPEZOIDAL



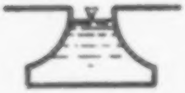
POEBING



APPROXIMATE EXPONENTIAL



APPROXIMATE LINEAR



PROPORTIONAL OR SUTRO

Figure 10. Various Sharp-Crested Weir Profiles

other profile for flows up to 283 ℓ/s (10 cfs). Sufficient head for these higher flow rates may pose a limitation for many sites, however, and in practice 113 ℓ/s (4 cfs) is often a more realistic upper bound.

Trapezoidal Weirs - Trapezoidal weirs of varying side angles have been used to measure liquid flows, but the most common one by far is the Cipolletti, whose sides incline outwardly at a slope of one horizontal to four vertical. Although the Cipolletti weir is a contracted weir, its discharge occurs essentially as though its end contractions were suppressed; thus the width of the crest can be used for flow calculations. It offers a wider range than either the rectangular or V-notch weir.

Other Weirs - Other weir profiles, as indicated in Figure 10, have been developed to achieve certain head-discharge relationships or to achieve some benefit peculiar to a particular type of site. None of these has been used or investigated as extensively as those discussed above, and consequently will not be dealt with here. There is one class of special profiles, however, that at least deserves passing mention. For situations where the normal range of discharges at a site might be easily handled by a V-notch weir but occasional larger flows would require, for example, a rectangular weir, the two profiles have been combined to form what is termed a compound weir, Figure 11.

Such a weir has a disadvantage, however. While flows may be measured rather accurately when the weir is essentially behaving as a V-notch weir, Figure 11a, or as a rectangular (either suppressed or contracted) weir, Figure 11b, there will be a transition zone where accurate readings will be difficult to achieve. When the discharge begins to exceed the capacity of the V-notch, thin sheets of liquid will begin to pass over the wide horizontal crests in a less than predictable fashion. This causes a discontinuity in the discharge curve. The size of the V-notch and the size of the rectangular notch should be selected so that discharge measurements in the transition range will be those of minimum importance.

Discussion - In order to have a satisfactorily-operating sharp-crested weir, the following general requirements should be considered:

a. The upstream face of the structure should be smooth and perpendicular to the axis of the channel in both horizontal and vertical directions.

b. The crest should be level, with a sharp right-angled edge on its upstream face; its thickness (in the direction of the flow) should not exceed 3 mm (1/8 in.) and should preferably be between 1 to 2 mm (0.04 to 0.08 in.). Knife edges should be avoided as they are too difficult to maintain.

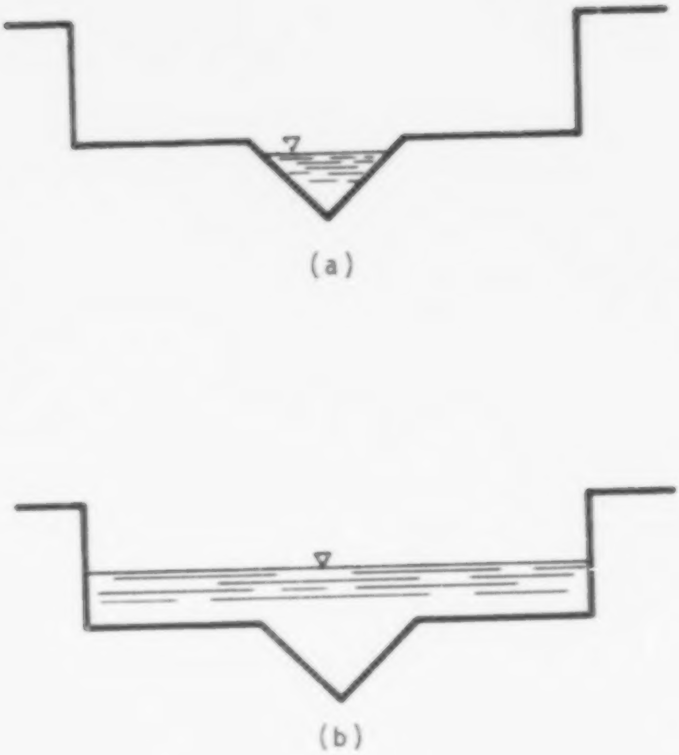


Figure 11. Compound Weir

c. The height of the crest above the approach channel bottom should never be less than 0.3m (1 ft); the minimum head should be at least 0.06m (0.2 ft). For a contracted rectangular weir, the distance from the sides of the weir to the sides of the approach channel should never be less than 0.3m (1 ft).

d. The cross-sectional area of the approach channel should be at least 8 times that of the nappe at the crest for a distance upstream of 15 to 20 times the height on the crest. If the weir pool is smaller than this, the velocity of approach may be too high and the gage readings too low; necessitating head corrections for velocity of approach.

e. The connection between the weir and the channel must be waterproof; i.e., all flow must pass over the weir, not around or under it.

In general, the sharp-crested weir is an inexpensive, accurate primary flow measuring device that is fairly easy to install. Laboratory accuracies approaching 1% of full scale have been achieved, but 5% is more typical of most good field installations. The operating range of a sharp-crested weir depends upon its profile, but 20:1 may be considered typical for many installations. The sharp-crested weir suffers from several deficiencies when considered for a storm or combined sewer application, however. It may well require construction of a weir box to obtain the proper flow approach to the weir. Sufficient head may not be available at the desired measuring site, and the head loss will be at least equal to the head measured. The crest of the weir must be kept clean. Fibers, stringy materials, and larger particles tend to cling to the crest and must be removed periodically.

Finally, because of its damming action, the sharp-crested weir will suffer from settling and accumulation of suspended solids in the approach channel behind the upstream face. This will lead to inaccurate readings. Some weirs have been constructed with a watertight door in the face on the channel bottom. When the door is opened the flow will go through this passage and tend to scour away collected sediment. However, most attempts to use charp-crested weirs in extremely dirty flows have been less than fully successful. Sharp-crested weirs are evaluated as a group in Table 11.

Submerged Orifices - The use of thin-plate orifice meters in pressurized conduit flow has already been discussed. In open channel flow, an orifice operates as a head-area device; in fact, if the water level drops below the top of the opening, it behaves like a weir and has been included here for that reason. Basically, it consists of a predetermined, sharp-edged opening in a plate affixed to a wall or other

TABLE 11. SHARP-CRESTED WEIR EVALUATION (ALL PROFILES)

	Evaluation Parameter	Scale		
1	Range	☐ Poor	☒ Fair	☐ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☒ Moderate	☐ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☒ Moderate	☐ Low
6	Effect of Solids Movement	☒ High	☐ Moderate	☐ Slight
7	Flow Obstruction	☒ High	☐ Moderate	☐ Slight
8	Head Loss	☒ High	☐ Medium	☐ Low
9	Manhole Operation	☐ Poor	☒ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☒ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☒ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☒ High	☐ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☒ Poor	☐ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☐ Medium	☒ Low
25	Portability	☐ No		☒ Yes

structure and through which flow may occur. Although any shape hole can be used, the most common are either circular or rectangular. Knowledge of the size and shape of the hole, the head acting on it, and the discharge condition (i.e., freely into air or under water) allows determination of the flow rate. Early orifices often discharged freely into air, but were practically abandoned as weirs become more common (and more extensively studied) because of the considerable head loss necessitated by their use.

The fall requirement is reduced if the orifice is lowered in the structure and discharges in the submerged condition. The submerged orifice is used where the head loss of a weir cannot be tolerated and a flume cannot be justified because of cost or some special conditions. Like the weir, a submerged orifice may be either contracted or suppressed. Suppression may occur on part (e.g., the bottom of a rectangular orifice flush with the channel flow) or all of the perimeter.

In selecting a channel site for use of a submerged orifice meter the distance from the edges of the orifice to the bounding surfaces of the channel, both on the upstream and downstream sides, should be greater than twice the least dimension of the orifice if contraction is to be assured. Also, the cross-sectional area of the water prism 6 to 9 m (20 to 30 ft) upstream from the orifice should be at least 8 times the cross-sectional area of the orifice. Velocity of approach to the orifice should be negligible, or correction must be made for velocity head.

An orifice should not be used in situations where weeds and trash are prevalent, as accumulation of submerged debris or of sand and sediment upstream may prevent accurate measurements. A clogged condition of an orifice is less visible than that of a weir and, so, may go undetected. Because of these factors and the small data base as compared to weirs and flumes, an orifice is not generally recommended for measurement of stormwater or combined sewage, even though its limited range of flow can be increased with the use of a metergate, which basically is a modified submerged orifice arranged so that the orifice is adjustable in cross-sectional area. Consequently, no further discussion or evaluation will be given.

Broad-Crested Weirs - If the weir notch is mounted in a wall too thick for the water to spring past, the weir is called broad-crested. A wide variety of shapes can be included under broad-crested weirs, and a wide variety of discharge coefficients will be encountered. A few such shapes are depicted in Figure 12. Broad-crested weirs, in practice, are usually pre-existing structures, such as dams, levees, diversion structures, etc. Discharge coefficients and discharge tables are usually obtained by calibrating the weir in place or by model studies. Broad-crested weirs are sometimes used where the sharp-crested weir causes undue maintenance problems. For example, problems with impact,

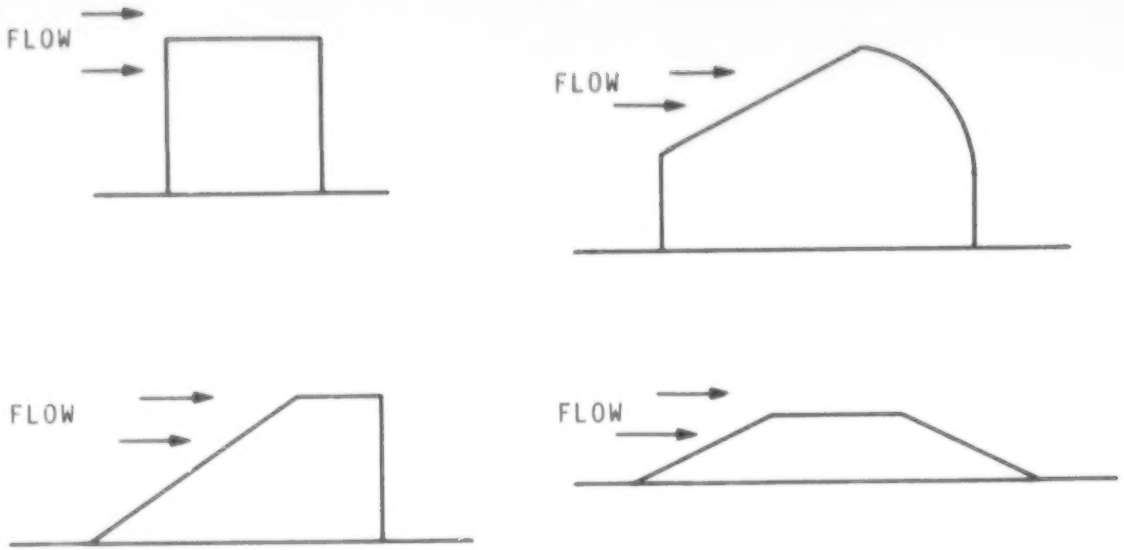

FLOW
FLOW
FLOW
FLOW

Figure 12. Examples of Broad-Crested Weir Shapes

abrasion, silting, etc. might indicate the need for a broad-crested weir. Broad-crested weirs are usually made of concrete or similar material and are not considered portable. In actuality, the notion of a broad-crested weir, which simply denotes a channel contraction made by a sill on the channel bottom, merges into that of a critical-depth flume. When properly designed and constructed, the broad-crested weir is governed by the same basic flow equations. Broad-crested weirs are evaluated in Table 12.

Flumes

Although the term "broad-crested weir" is widely used to denote a channel constriction made by some sort of a sill on the channel bottom, other open channel constrictions, generally called flumes, have been used to measure discharges since the beginning of the century. Most flumes in common use today can be traced to one of three early design sources: rectangular English flumes based upon early work in India around 1908-1914 and the writings of F. V. A. E. Engal (23); the Parshall flume whose forerunner, a venturi flume developed by Cone (24), was extensively modified and tested by Parshall (25, 26); and flumes of the type first developed by Palmer and Bowlus (27).

Flumes can be categorized as belonging to one of three general families depending upon the state of flow induced - subcritical, critical, or supercritical. By definition the critical flow state is that for which the Froude number is unity. This is the state of flow at which the specific energy is minimum for a given discharge. When critical depth occurs in a channel (either at a constriction or in a regular cross-section), one head measurement can indicate discharge rate if it is made far enough upstream so that the flow depth is not affected by the drawdown of the water surface as it heads to achieve the critical state of flow.

Kilpatrick (28) identifies six approaches employed in various flume designs, and these will be briefly treated below following his discussion.

Type I, tranquil-flow, small-width reduction flumes are typical of the earliest measuring flumes and are depicted in Figure 13. Subcritical flow enters the flume, and the side contractions reduce the width, resulting in an increase in unit discharge. Because there is no change in bed elevation, and minor energy loss, the specific energy in the throat is about the same as in the approach. With constant specific energy, the effect of a small width contraction is a lowering of the water surface in the throat but, owing to the small degree of contraction, critical depth is not accomplished. It is necessary in this type of flume to measure the head in both the approach section and in the throat.

TABLE 12. BROAD-CRESTED WEIR EVALUATION

Evaluation Parameter		Scale		
1	Range	☐ Poor	☒ Fair	☐ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☒ High	☐ Moderate	☐ Low
6	Effect of Solids Movement	☒ High	☐ Moderate	☐ Slight
7	Flow Obstruction	☐ High	☒ Moderate	☐ Slight
8	Head Loss	☐ High	☒ Medium	☐ Low
9	Manhole Operation	☐ Poor	☐ Fair	☒ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☒ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☒ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☐ Medium	☒ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☒ No		☐ Yes
21	Ease of Calibration	☐ Poor	☒ Fair	☐ Good
22	Maintenance of Calibration	☐ Poor	☒ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☐ Medium	☒ Low
25	Portability	☒ No		☐ Yes

Type II, critical-flow, large-width reduction flumes are illustrated in Figure 14 and differ from Type I flumes only in that the throat contraction is sufficient to ensure that critical flow is achieved. This gives the advantage of requiring measurement at only one location, which may be either in the immediate approach to the flume or in the throat. Measurement in the approach will yield a more sensitive stage-discharge relationship because changes in discharge will result in greater changes in depth in subcritical flow than would like changes in discharges in critical flow. Unfortunately, the stage-discharge relationship in the approach may be unstable due to approach conditions such as scour and fill. Consequently, stage is usually measured in the throat to alleviate influence from either upstream or downstream. Approach conditions can have some effect on flow in the throat, but it is generally insignificant. The site at which critical depth is first reached may shift further downstream into the throat as a result of excessive deposition in the approach. For this reason, and to avoid possible flow separations near the entrance, stage measurements in the throat should not be too close to the entrance. Flow close to critical is very unstable, constantly attempting to become either subcritical or supercritical. Therefore, this type of flume is seldom encountered in practice.

Type III, tranquil-flow, small-increase-in-bed elevation flumes are shown in Figure 15. Because of the requirement for dual gaging points and the partial barrier to the approaching flow, which will encourage deposition of suspended solids, such designs are not commonly used.

Type IV, supercritical-flow, width-reduction, steep-slope flumes are illustrated in Figure 16. For flumes that have bed slopes of near zero, critical depth is the minimum depth possible in the flume. Further contraction, either at the sides or bottom, will not produce supercritical flow. This can be accomplished only by increasing the available specific energy from the approach into the throat. For Type IV flumes, the bed is placed on a slope sufficient to cause the required increase in specific energy to produce supercritical flow in the throat. It may be thought of as a Type II flume tilted in the downstream direction. Only a single gaging point is required.

Type V, supercritical-flow, width-reduction, drop-in-bed flumes are depicted in Figure 17. Here the increase in specific energy required to achieve supercritical flow is provided by a sudden drop in the bed. Measurement of head is made either in the throat or the approach. A discharge rating based upon measurements in the region of supercritical flow, while not as sensitive as compared with measurements in subcritical flow, is the least influenced by disturbances either upstream or downstream, and hence is apt to be the most stable. Similarly, such flumes are the most capable of stable operation up to high submergences.

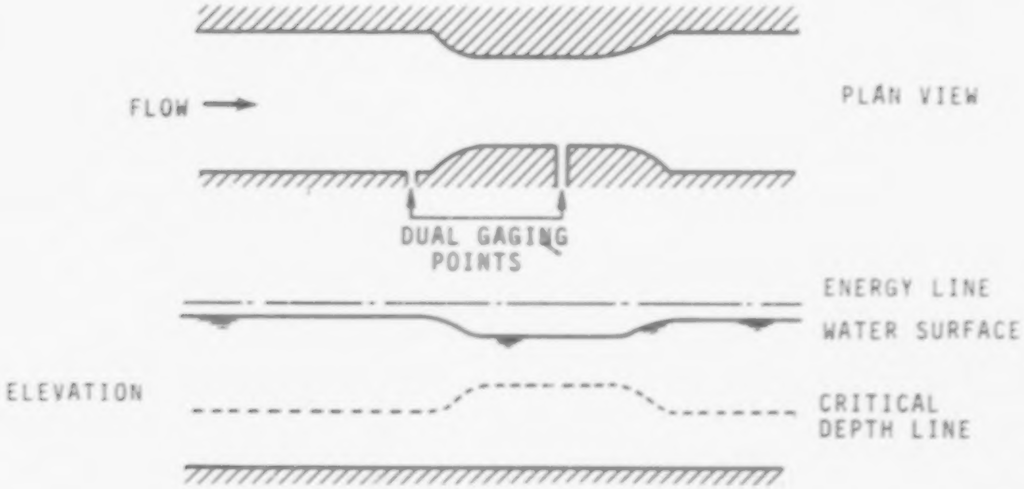

FLOW
PLAN VIEW
DUAL GAGING POINTS
ENERGY LINE
WATER SURFACE
ELEVATION
CRITICAL DEPTH LINE

Figure 13. Type I Flume - Critical Flow Contraction Obtained by Small Width Reduction, Horizontal Bed

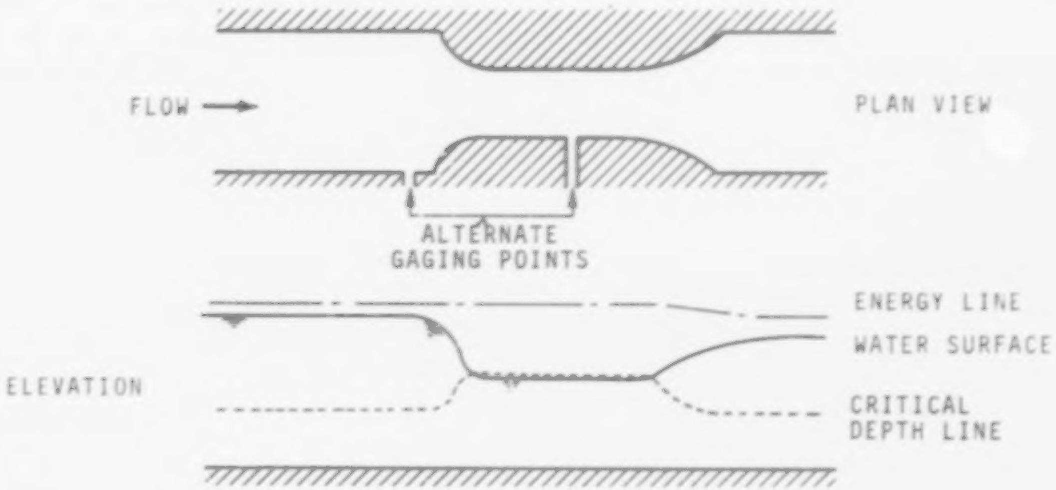

FLOW
PLAN VIEW
ALTERNATE GAGING POINTS
ENERGY LINE
WATER SURFACE
ELEVATION
CRITICAL DEPTH LINE

Figure 14. Type II Flume - Critical Flow Contraction Obtained by Large Width Reduction, Horizontal Bed

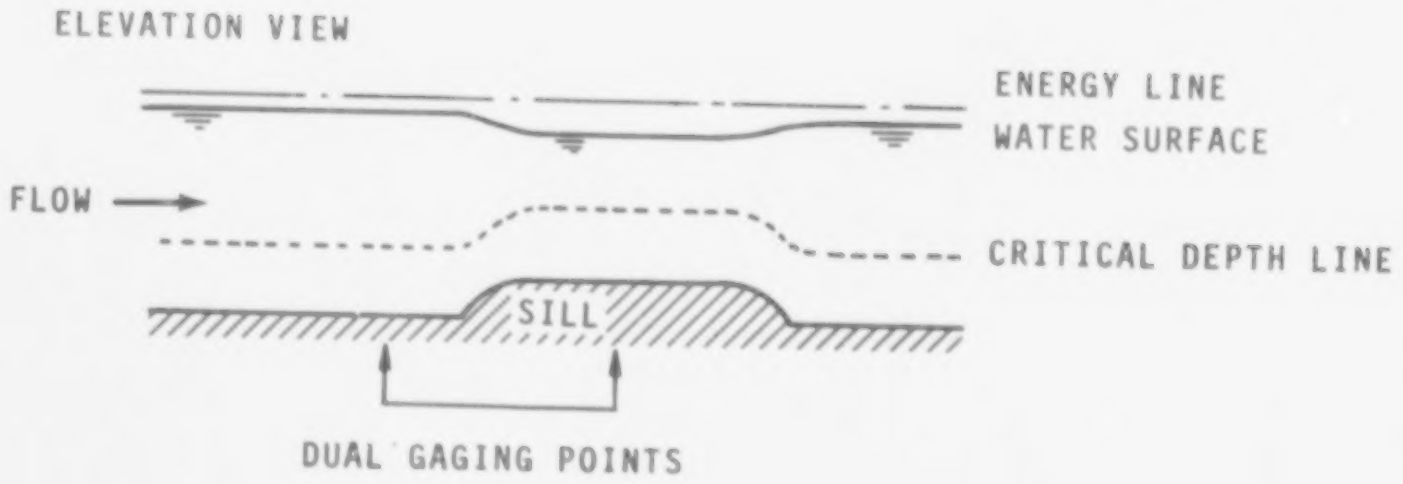

ELEVATION VIEW
ENERGY LINE
WATER SURFACE
FLOW
CRITICAL DEPTH LINE
SILL
DUAL GAGING POINTS

Figure 15. Type III Flume - Subcritical Flow Contraction Obtained By Small Increase In Bed Elevation, Horizontal Bed

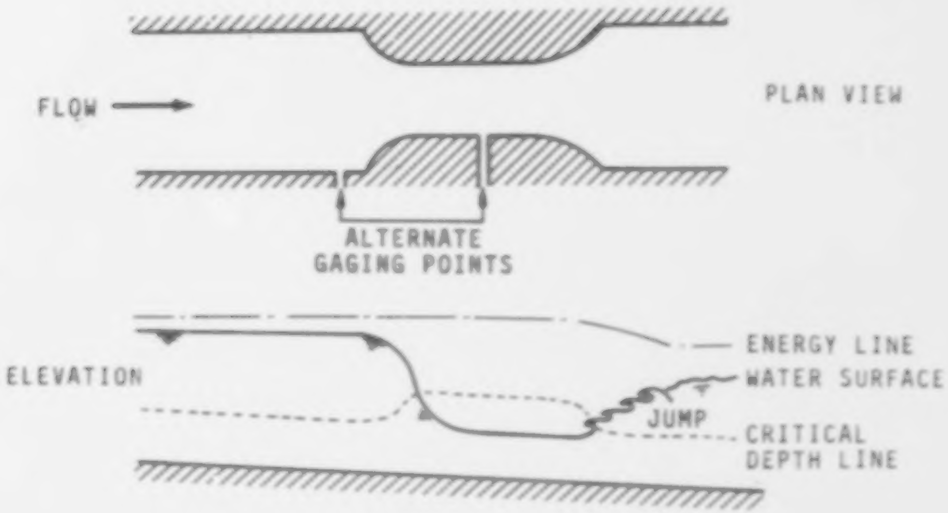

PLAN VIEW
FLOW
ALTERNATE GAGING POINTS
ELEVATION
ENERGY LINE
WATER SURFACE
JUMP
CRITICAL DEPTH LINE

Figure 16. Type IV Flume - Supercritical Flow Contraction Obtained by Width Reduction and Sloping Bed

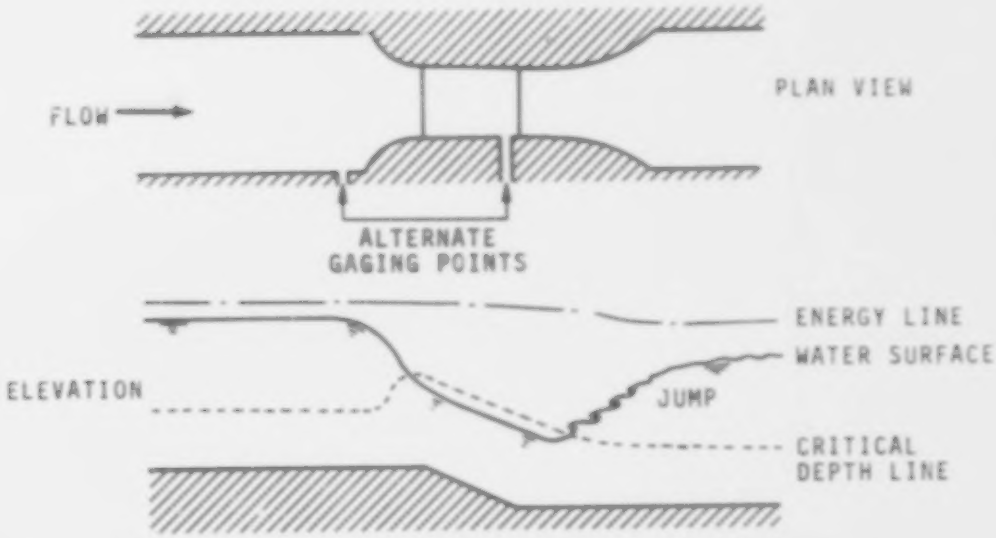

PLAN VIEW
FLOW
ALTERNATE GAGING POINTS
ELEVATION
ENERGY LINE
WATER SURFACE
JUMP
CRITICAL DEPTH LINE

Figure 17. Type V Flume - Supercritical Flow Contraction Obtained by Width Reduction and Drop in Bed

Type VI, supercritical-flow, steep-slope flumes are illustrated in Figure 18. Here there is no contraction, the increase in specific energy necessary for achieving supercritical flow being produced simply by producing sufficient downstream slope. Although a slope of one degree is usually sufficient to produce critical depth in the vicinity of the upstream edge of the apron, waves and disturbances are apt to be numerous downstream. For this reason slopes on ordinary concrete aprons will more typically range from 2 to 5%.

Site Selection - A few recommendations for the selection of gaging sites apply in general to all types of commonly-encountered flumes. The flumes should be located in a straight section of channel without bends immediately upstream. The approaching flow should be well distributed across the channel, and relatively free of turbulence, eddies, and waves. Generally, a site with high velocity of approach should not be selected. But, if the water surface just upstream is smooth with no surface boils, waves, or high-velocity current concentrations, accuracy may not be greatly affected by velocity of approach.

Consideration should be given to the height of upstream banks, noting their ability to sustain the increased depth caused by the flume installation. Although less head is lost through flumes than over weirs, particularly if flat-bottomed flumes are used, losses may be significant with large installations. The possibility of submergence of the flume due to backwater from downstream must also be investigated, although the effect of submergence upon the accuracy of most flumes is much less than is the case with weirs.

Subcritical (Venturi) Flumes - Subcritical flumes are called true venturi type flumes by some researchers, e.g., Replogle (8), probably because of their requirement for the measurement of flow levels at two positions. The Type I and III flumes discussed earlier are examples of designs of such devices. Because of their advantage of requiring only a single measurement, supercritical flumes are generally preferred design approaches and, consequently, subcritical flumes are not often installed today. They are evaluated in Table 13.

Parshall Flume - The development of many early flumes arose from the need to measure irrigation flows, and the Parshall flume is no exception. The earlier designs were Types I, II, and III flumes, and the essential change introduced by Parshall was a drop in the floor which produced supercritical flow through the throat (Type V). Today the Parshall flume is the most widely used primary device in the head-area classification for the measurement of sewage and other wastewater. The configuration and standard nomenclature for Parshall flumes is given in Figure 19. For a given throat width (W), all other dimensions are rigidly prescribed. Since the rating tables for Parshall flumes are based upon extensive and meticulous research, faithful adherence to all dimensions is necessary to achieve accuracy.

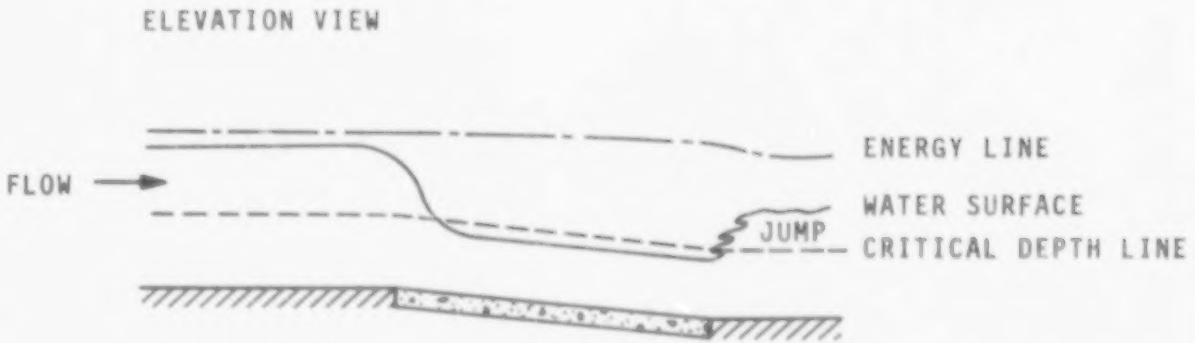
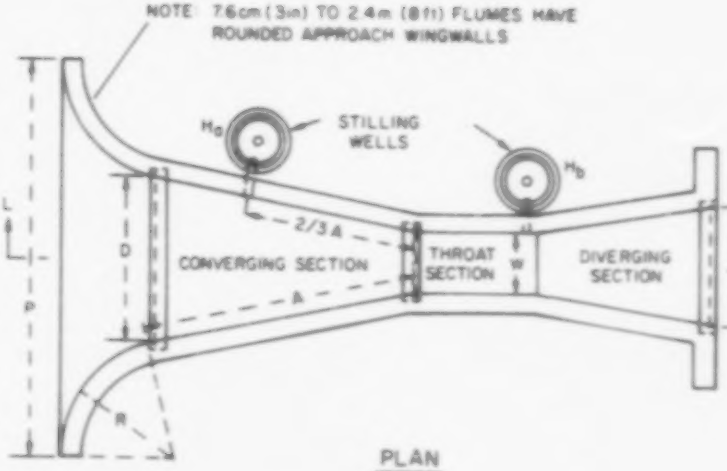

ELEVATION VIEW
FLOW
ENERGY LINE
WATER SURFACE
JUMP
CRITICAL DEPTH LINE

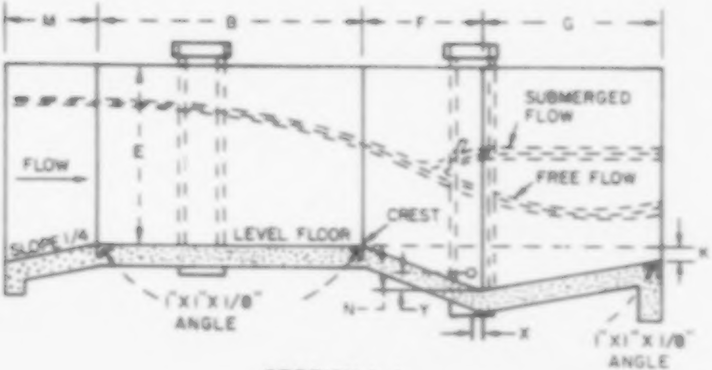
Figure 18. Type VI Flume - Supercritical Flow Contraction Obtained By Steepening Slope

TABLE 13. SUBCRITICAL (VENTURI) FLUME EVALUATION

Evaluation Parameter		Scale		
1	Range	☐ Poor	☒ Fair	☐ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☐ Moderate	☒ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☒ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☒ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☒ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☐ Medium	☒ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☒ Medium	☐ Low
25	Portability	☒ No		☐ Yes


NOTE: 7.6cm (3in) TO 2.4m (8ft) FLUMES HAVE ROUNDED APPROACH WINGWALLS
STILLING WELLS
H_a
H_b
L
D
P
R
2/3 A
A
CONVERGING SECTION
THROAT SECTION
W
DIVERGING SECTION
L
C

PLAN


M
B
F
G
E
FLOW
SUBMERGED FLOW
FREE FLOW
CREST
SLOPE 1/4
LEVEL FLOOR
1"X1"X1/8" ANGLE
N
Y
X
K
1"X1"X1/8" ANGLE

SECTION L-L

LEGEND:

W	Size of flume, in inches or feet.
A	Length of side wall of converging section.
2/3A	Distance back from end of crest to gage point.
B	Axial length of converging section.
C	Width of downstream end of flume.
D	Width of upstream end of flume.
E	Depth of flume.
F	Length of throat.
G	Length of diverging section.
K	Difference in elevation between lower end of flume and crest.
N	Depth of depression in throat below crest
R	Radius of curved wing wall.
M	Length of approach floor.
P	Width between ends of curved wing walls.
X	Horizontal distance to H_b gage point from low point in throat.
Y	Vertical distance to H_b gage point from low point in throat.

Figure 19. Configuration and Standard Nomenclature for Parshall Flumes

The earlier Parshall flumes were developed in sizes (throat widths) ranging from 7.6 cm (3 in.) to 2.4m (8 ft). More recently, Robinson (29) has calibrated Parshall flumes of 2.5 cm (1 in.) and 5.1 cm (2 in.) in size. Flumes with throat widths of 3 to 15m (10 to 50 ft) have been constructed and field calibrated. Head-discharge ratings are thus available for a large range in throat width. Table 14 is presented to give the reader a "feel" for the dimensions and capacities of all sizes of standard Parshall flumes.

Flow through a Parshall flume may be either free or submerged. In free flow, only the upstream head (Ha) need be measured, and this condition is favored for accurate measurement. Where free-fall conditions exist for all flows, the downstream (Hb) may be omitted and the entire diverging section left off if desired, assuming channel erosion is no problem. This simplification has been used in the design of small portable Parshall flumes.

Submerged flow exists when the water surface elevation downstream of the flume is high enough to affect the head and retard the rate of discharge. The degree of submergence is indicated by the ratio of the downstream head to the upstream head (Hb/Ha). If the ratio is greater than 0.6 for flumes under 0.3m (1 ft) or 0.7 for flumes in the 0.3 to 2.4m (1 to 8 ft) range, flow must be considered to be submerged and corrections must be made according to the degree of submergence. A complete treatment of the subject is given by Skogerboe, et al (30, 31).

Small solids in suspension are readily carried through Parshall flumes and do not affect the measurement accuracy, which should range between 1.5 percent (virtually the best obtainable) to 5 percent (more typical of good field installations). Errors greater than this are frequently found, the chief causes being either dimensional inaccuracies or improper flow conditions. Although Parshall flumes are self-cleaning, large rocks and other debris in the flow may cause problems. Kilpatrick (28) notes that, "*its use on flashy, cobble-strewn streams has been relatively unsuccessful.*" Another problem with the use of a Parshall flume in measuring dirty flows such as sewage is that sometimes the installation must differ from the standard so as to prevent deposition of material upstream from the flume. Such non-standard entrance transitions can result in discharges that are quite different from standard values as pointed out by Chen, et al (32).

The head loss required for flow measurement with a Parshall flume is quite small. There must be a way to achieve the required drop in the floor, however, and this will eliminate some sites from consideration. Parshall flumes are evaluated in Table 15.

Palmer-Bowlus Flume - Flumes of the type first suggested and developed by Palmer and Bowlus (27) are a form of Type IV flume, being dependent

TABLE 14. STANDARD PARSHALL FLUME DIMENSIONS AND CAPACITIES

Widths			Axial Leugths			Wall Depth in Con-verging Section	Vertical Distance Below Crest		Con-verging Wall Length	Gage Points			Free Flow Capacities	
Size: Throat Width	Up-stream End	Down-stream End	Con-verging Section	Throat Section	Diverging Section		Dip at Throat	Lower End of Flume		Ha, Dist Upstream of Crest**	Hb		Min	Max
W	D	C	B	F	G	E	N	K	A*		x	y		
Inches	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	cfs	cfs
1	0.549	0.305	1.17	0.250	0.67	0.5-0.75	0.094	0.062	1.19	0.79	0.026	0.042	0.005	0.15
2	.700	.443	1.33	.375	.83	0.50-0.83	.141	.073	1.36	.91	.052	.083	.01	.30
3	.849	.583	1.50	.500	1.00	1.00-2.00	.188	.083	1.53	1.02	.083	.125	.03	1.90
6	1.30	1.29	2.00	1.00	2.00	2.0	.375	.25	2.36	1.36	.167	.25	.05	3.90
9	1.88	1.25	2.83	1.00	1.50	2.5	.375	.25	2.88	1.93	.167	.25	.09	8.90
Feet														
1.0	2.77	2.00	4.41	2.0	3.0	3.0	.75	.25	4.50	3.00	.167	.25	.11	16.1
1.5	3.36	2.50	4.66	2.0	3.0	3.0	.75	.25	4.75	3.17	.167	.25	.15	24.6
2.0	3.96	3.00	4.91	2.0	3.0	3.0	.75	.25	5.00	3.33	.167	.25	.42	33.1
3.0	5.16	4.00	5.40	7.0	3.0	3.0	.75	.25	5.50	3.67	.167	.25	.61	50.4
4.0	6.35	5.00	5.88	2.0	3.0	3.0	.75	.25	6.00	4.00	.167	.25	1.30	67.9
5.0	7.55	6.00	6.38	2.0	3.0	3.0	.75	.25	6.50	4.33	.167	.25	1.60	85.6
6.0	8.75	7.00	6.86	2.0	3.0	3.0	.75	.25	7.0	4.67	.167	.25	2.60	103.5
7.0	9.95	8.00	7.35	2.0	3.0	3.0	.75	.25	7.5	5.0	.167	.25	3.00	121.4
8.0	11.15	9.00	7.84	2.0	3.0	3.0	.75	.25	8.0	5.33	.167	.25	3.50	139.5
10	15.60	12.00	14.0	3.0	6.0	4.0	1.12	.50	9.0	6.00			6	300
12	18.40	14.67	16.0	3.0	8.0	5.0	1.12	.50	10.0	6.67			8	520
15	25.0	18.33	25.0	4.0	10.0	6.0	1.50	.75	11.5	7.67			8	900
20	30.0	24.00	25.0	6.0	12.0	7.0	2.25	1.00	14.0	9.33			10	1340
25	35.0	29.33	25.0	6.0	13.0	7.0	2.25	1.00	16.5	11.00			15	1660
30	40.4	34.67	26.0	6.0	14.0	7.0	2.25	1.00	19.0	12.67			15	1990
40	50.8	45.33	27.0	6.0	16.0	7.0	2.25	1.00	24.0	16.00			20	2640
50	60.8	56.67	27.0	6.0	20.0	7.0	2.25	1.00	29.0	19.33			25	3280

* For sizes 1' to 8', A = W/2 + 4.

** Ha located 2/3 A distance from crest for all sizes; distance is wall length, not axial.

Notes:
1. Flume sizes 3 inches through 8 feet have approach aprons rising at a 1:4 slope and the following entrance roundings: 3 through 9 inches, radius = 1.33 feet; 1 through 3 feet, radius = 1.67 feet; 4 through 8 feet, radius = 2.00 feet.
2. To maximize clarity, equivalent SI units are not given.
3. Table prepared by Kilpatrick (28).

TABLE 15. PARSHALL FLUME EVALUATION

	Evaluation Parameter	Scale		
1	Range	☐ Poor	☐ Fair	☒ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☒ Moderate	☐ Low
6	Effect of Solids Movement	☐ High	☐ Moderate	☒ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☒ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☒ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☒ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☐ Medium	☒ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☒ Medium	☐ Low
25	Portability	☐ No		☒ Yes

upon existing conduit slope and a channel contraction (provided by the flume) to produce supercritical flow. Ludwig and Ludwig (33) and Wells and Gotaas (34) have discussed various design aspects of such flumes. Such flumes arose out of a desire to have a measurement device that could be inserted into an existing conduit with minimal site requirements other than sufficient slope. A number of different cross-section shapes have been used over the years. Typical shapes for round and rectangular conduits are depicted in Figure 20. A proprietary flume, the Leopold-Lagco, which was introduced in 1965, is a Palmer-Bowlus type flume with a rectangular cross-section and is designed for use with circular pipes.

In the detailed laboratory studies conducted by Wells and Gotaas (34), they found that accuracies within ±3% of the theoretical rating curve could be obtained at depths as great as 90% of the pipe diameter. No effect of downstream depth on calibration was found for submergence ratios less than 0.85. Various geometric effects were investigated, and it was found that a minimum throat length of at least 60 percent of the pipe diameter was required, that the base height and exit transitions had no effect on the calibration, that a variation of entrance transition slope from 1:3 to 1:2 had a negligible effect, and that the point of upstream depth measurement should be no more than half of the pipe diameter upstream from the entrance to the flume.

In some designs, e.g., Figure 20c, the bottom slab or base is omitted entirely. It is more often included, however, both to help distribute the overall channel contraction and to provide structural integrity, an important feature for portable devices especially.

The chief advantage of Palmer-Bowlus flumes over Parshall flumes is their ease of installation in existing conduits. They may also offer somewhat lower head loss. They share all of the benefits listed in the discussion of Parshall flumes. In ordinary designs operating under low flow conditions, the bottom slab acts as a broad-crested weir, whose characteristics were discussed earlier. A disadvantage of Palmer-Bowlus flumes is that they have a smaller range, with 20:1 being seldom exceeded. Standard Palmer-Bowlus flumes are available to fit pipe sizes from 15.2 cm (6 in.) to 2.4m (8 ft). Palmer-Bowlus flumes are evaluated in Table 16.

As stated by Palmer and Bowlus (27), "*The important factor in the construction and installation of any form of venturi device is that a constriction of some sort be placed in the channel to produce critical velocity with the least loss of energy, and that the shape, size, and dimensions of the device are important only insofar as they meet the specific problem at hand in a practical manner.*" Diskin (35) has introduced an unconventional sort of a Palmer-Bowlus flume, Figure 21. He achieved channel contraction by wedging a pier-shaped element in

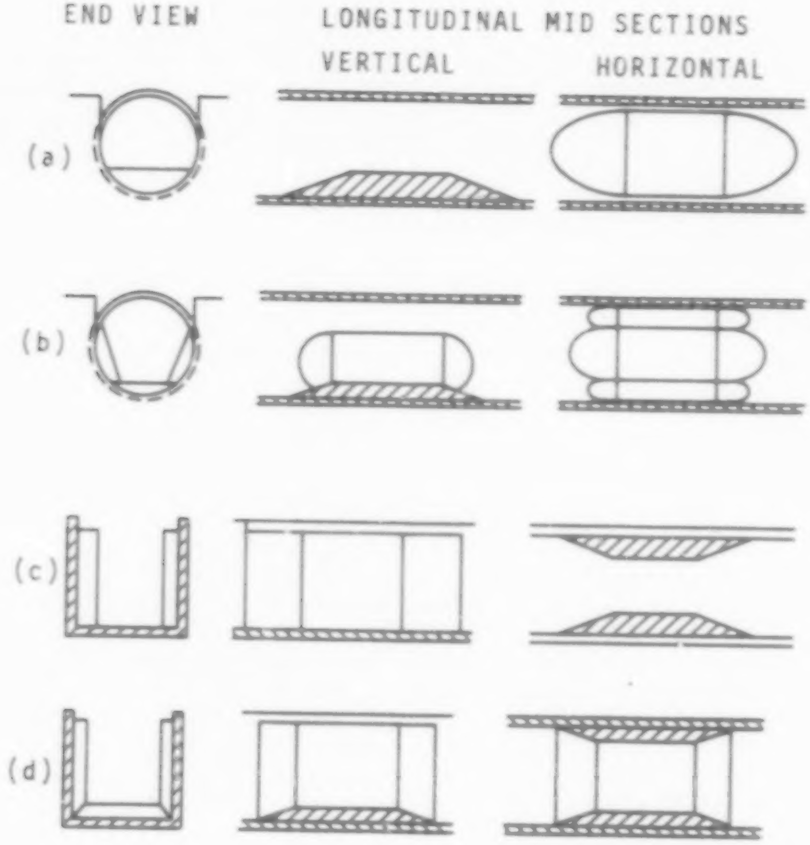

END VIEW
LONGITUDINAL MID SECTIONS
VERTICAL
HORIZONTAL
(a)
(b)
(c)
(d)

Figure 20. Various Cross-Section Shapes of Palmer-Bowlus Flumes

TABLE 16. PALMER-BOWLUS FLUME EVALUATION

	Evaluation Parameter	Scale		
1	Range	☐ Poor	☒ Fair	☐ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☒ Moderate	☐ Low
6	Effect of Solids Movement	☐ High	☐ Moderate	☒ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☐ Fair	☒ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☐ Moderate	☒ Slight
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☒ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☐ Medium	☒ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☐ Medium	☒ Low
25	Portability	☐ No		☒ Yes

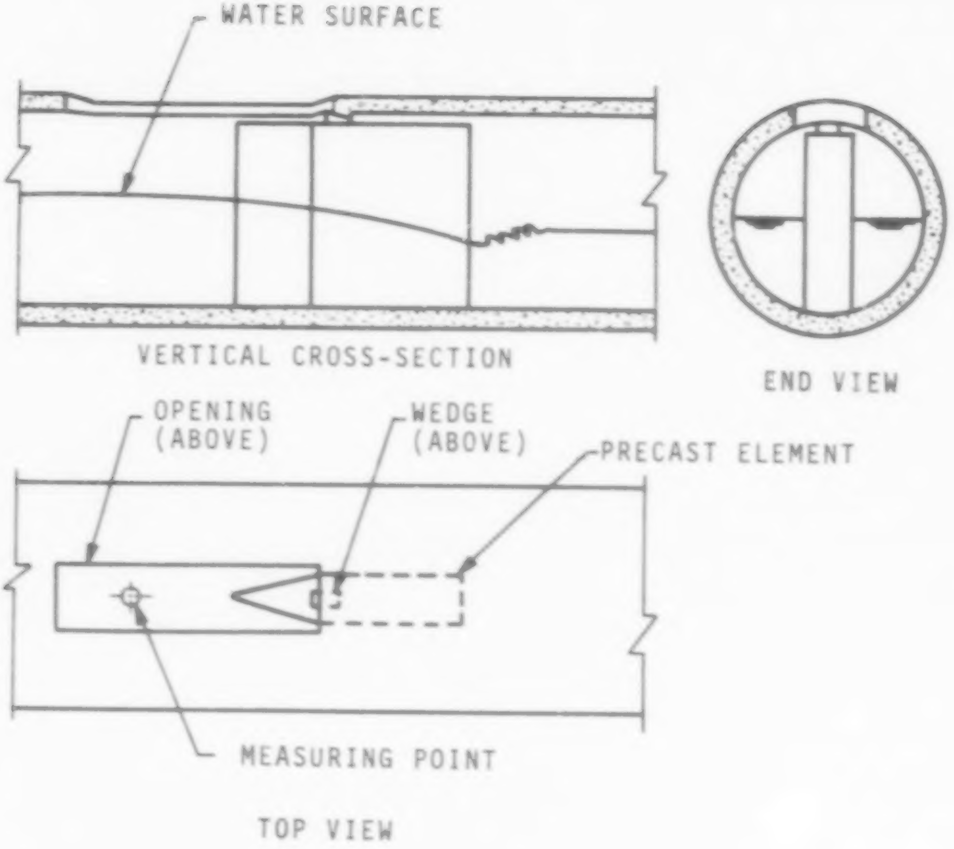

WATER SURFACE
VERTICAL CROSS-SECTION
END VIEW
OPENING (ABOVE)
WEDGE (ABOVE)
PRECAST ELEMENT
MEASURING POINT
TOP VIEW

Figure 21. Diskin Measuring Device

the pipe between the crown and the invert. Experimental observations confirmed the theoretical rating curve determined under the same assumptions as for a standard Palmer-Bowlus flume. Limiting submergence was found to be between 0.75 and 0.85.

The chief drawback to such a metering device is that it poses a severe obstruction to the flow and, if applied to trashy or debris-laden flows, it almost surely invites, in time, either its own destruction or blockage of the conduit. As a portable device, however, it can be installed quickly and may have some use. The Diskin device is evaluated in Table 17.

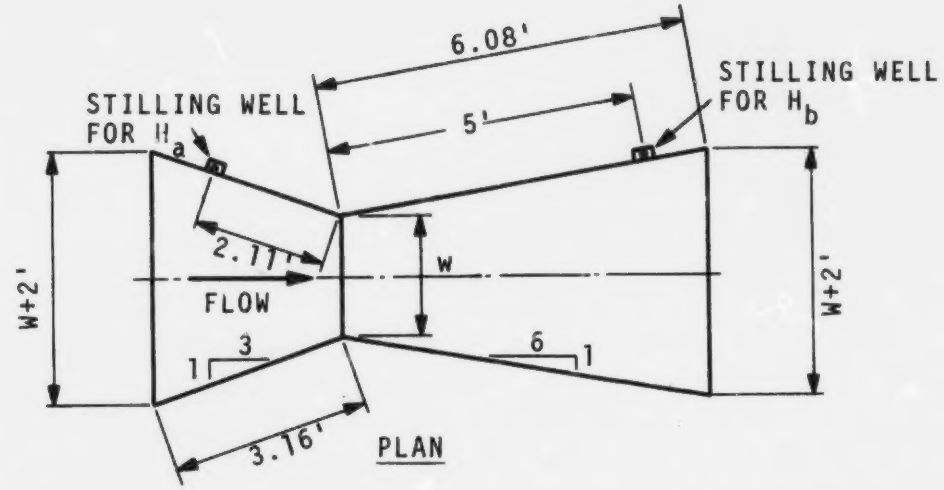
Cutthroat Flume - The cutthroat flume was developed for use in flat gradient channels where a flume which could operate satisfactorily under both free (critical) flow and submerged flow conditions might be desired. It operates as either a Type I or Type II flume. The advantages of a flume with a level floor are that it is easy to construct and can be placed inside an existing channel without requiring excavation, simply by placing it on the channel bed. Studies reported by Skogerboe, et al (30) showed that flow depths measured in the exit section of the flume resulted in more accurate submerged flow calibration curves than calibrations employing flow depths measured in the throat section. Since the upstream depth measurement is made near the entrance, there is no need for a throat section in such a flume; in fact, removing the throat section was found to improve flow conditions in the exit section. Skogerboe, et al (36), who performed the development work on these flumes, have given the name "Cutthroat" to any such flume that has no throat section (i.e., zero throat length). A rectangular cutthroat flume is illustrated in Figure 22.

One of the benefits of a cutthroat flume is economy, since fabrication is facilitated by the flat bottom and removal of the throat section. Another fabrication advantage is that every flume size has the same wall lengths, which allows the same forms or patterns to be used for every flume size. Rectangular cutthroat flume sizes of 0.3, 0.6, 0.9, 1.2, and 1.8m (1, 2, 3, 4, and 6 ft) have been studied extensively by Skogerboe, et al (36). Transition submergences were found to vary smoothly from 79% to 88% over this range. Above these values, the flow is subcritical (submerged) and the submerged flow calibration curves must be used.

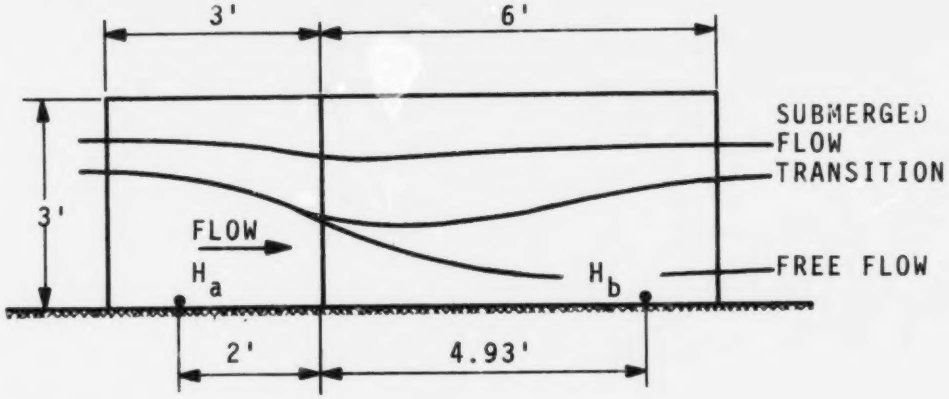
Similar cutthroat flumes of a trapezoidal shape with sides sloping outward at 45 degrees were also investigated by Skogerboe, et al (36) in small sizes, i.e., throat widths of 0, 15, and 30 cm (0, 6, and 12 in.). Development of intermediate and larger sizes was not attempted because of the variety of possible geometries that could be used. Cutthroat flumes are evaluated in Table 18.

TABLE 17. DISKIN DEVICE EVALUATION

Evaluation Parameter		Scale		
1	Range	☐ Poor	☒ Fair	☐ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☒ Moderate	☐ Low
6	Effect of Solids Movement	☐ High	☒ Moderate	☐ Slight
7	Flow Obstruction	☒ High	☐ Moderate	☐ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☐ Fair	☒ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☐ Moderate	☒ Slight
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☒ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☒ No		☐ Yes
15	Maintenance Requirements	☒ High	☐ Medium	☐ Low
16	Adverse Ambient Effects	☒ High	☐ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☒ Fair	☐ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☒ Fair	☐ Good
22	Maintenance of Calibration	☐ Poor	☒ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☐ Medium	☒ Low
25	Portability	☐ No		☒ Yes


6.08'
STILLING WELL
FOR H_b
STILLING WELL
FOR H_a
5'
2.11'
W+2'
w
FLOW
1
3
6
1
3.16'
W+2'

PLAN


3'
6'
SUBMERGED
FLOW
TRANSITION
3'
FLOW
H_a
H_b
FREE FLOW
2'
4.93'

ELEVATION

Figure 22. Rectangular Cutthroat Flume

TABLE 18. CUTTHROAT FLUME EVALUATION

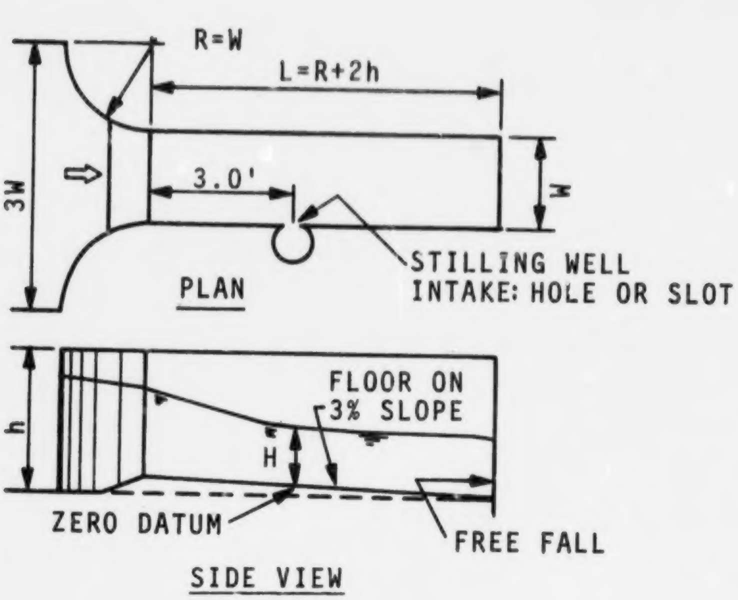
Evaluation Parameter		Scale		
1	Range	☐ Poor	☐ Fair	☒ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☐ Moderate	☒ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☒ Poor	☐ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☐ Moderate	☒ Slight
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☒ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☐ Medium	☒ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☐ Medium	☒ Low
25	Portability	☒ No		☐ Yes

Other Flumes - Several other flume designs have been used to solve specific problems. These flumes may: (a) be easier to construct for certain types of sites; (b) pass sediment-laden flows more readily; (c) handle a wider range of flows under certain conditions; (d) have increased sensitivity in a particular flow range; etc. As a general rule, they have not been as extensively investigated as the Parshall or Palmer-Bowlus flumes, and less is known about their behavior over a wide range of conditions.

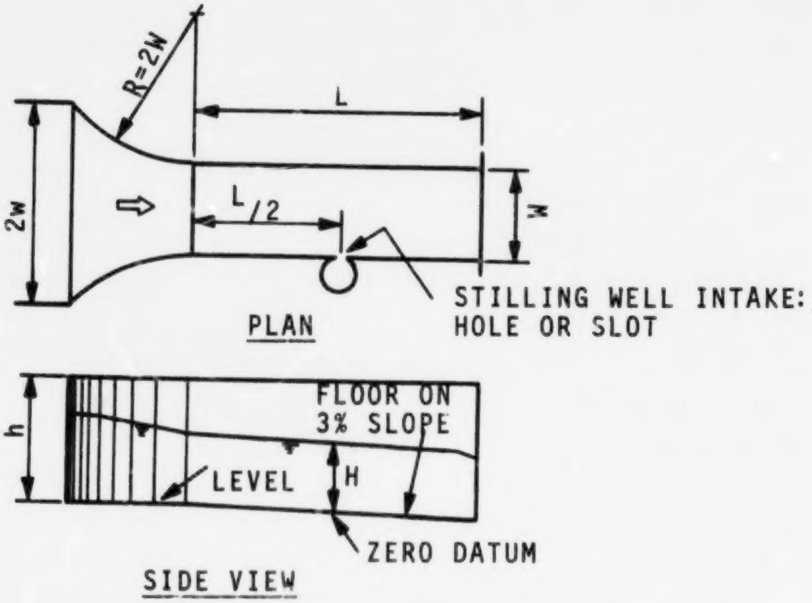
San Dimas Flumes - As an example, the San Dimas flume was developed to measure debris-laden flows in the San Dimas Experimental forest in 1938. It is a modified Type IV flume in that it uses lateral contraction plus a 3% slope in its floor to create a supercritical flow. In the entry, the floor rises quickly to the crest, after which it falls as indicated in Figure 23a. Because head measurements are made in supercritical flow in the throat and critical depth occurs upstream, the discharge ratings should be independent of upstream and downstream distubances. Variation in approach conditions also should have little effect on the ratings. Because of its rectangular cross-section, the San Dimas flume is not sensitive or accurate at low flows. Results of tests on modified San Dimas flumes were reported by Bermel (37), who reduced the degree of contraction of the flume relative to the natural channel, provided a less abrupt entrance, and measured the head at the midpoint of the flume regardless of length. The modified San Dimas flume is depicted in Figure 23b. San Dimas flumes are evaluated in Table 19.

Trapezoidal Flumes - In attempts to obtain wider ranges of discharge than those that can be obtained with Parshall or San Dimas flumes, several investigators have considered supercritical trapezoidal flumes. These generally operate as Type IV flumes. The outward sloping of the flume walls provides increased sensitivity to lower discharge rates for a given size and, hence, increased range. The possible elements of a trapezoidal flume are indicated in the isometric sketch in Figure 24. All of these elements need not be included in a particular design, however. In the trapezoidal cutthroat flume discussed earlier, for example, the throat section is absent. Other designs eliminate the diverging and exit sections where channel erosion is not a problem, and so on.

Serious investigations of trapezoidal flumes began to be reported in increasing numbers in the late 1950s. Geometric variations are so numerous that no attempt will be made here to describe them all. Robinson (38) has extensively investigated a trapezoidal flume with a flat floor throughout the flume that conforms to the general slope of the channel. Other designs, such as the one reported by Gwinn (39), have the floor sloping slightly towards the center to form a very shallow "V".


R=W
L=R+2h
3W
3.0'
W
STILLING WELL
INTAKE: HOLE OR SLOT
PLAN
h
FLOOR ON
3% SLOPE
H
ZERO DATUM
FREE FALL
SIDE VIEW

a. Original San Dimas Flume


R=2W
L
2W
L/2
W
STILLING WELL INTAKE:
HOLE OR SLOT
PLAN
h
FLOOR ON
3% SLOPE
LEVEL
H
ZERO DATUM
SIDE VIEW

b. Modified San Dimas Flume

Figure 23. San Dimas Flumes

TABLE 19. SAN DIMAS FLUME EVALUATION

Evaluation Parameter		Scale		
1	Range	☐ Poor	☐ Fair	☒ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☐ Moderate	☒ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☒ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☐ Moderate	☒ Slight
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☒ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☐ Medium	☒ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☐ Medium	☒ Low
25	Portability	☒ No		☐ Yes

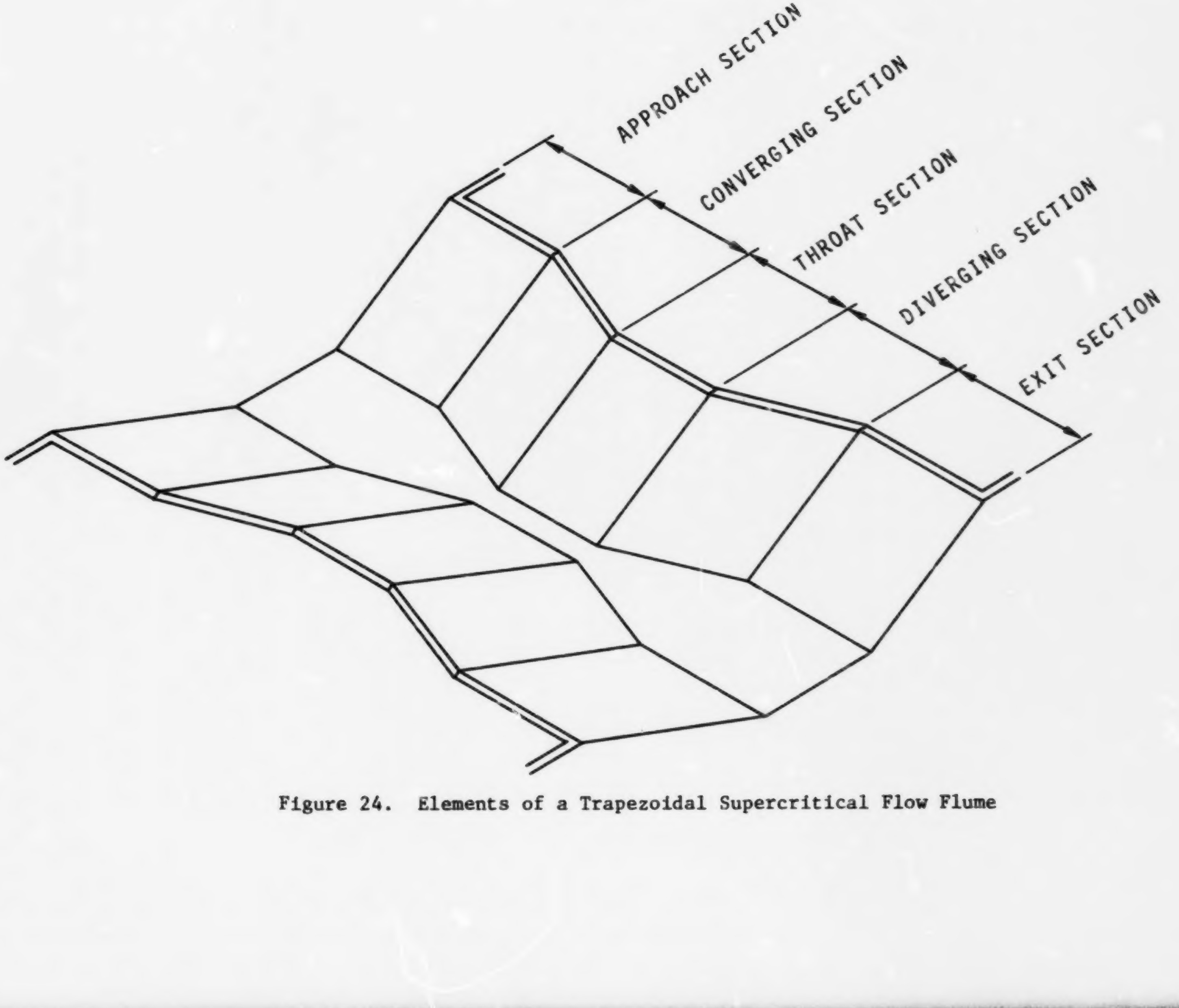

APPROACH SECTION
CONVERGING SECTION
THROAT SECTION
DIVERGING SECTION
EXIT SECTION

Figure 24. Elements of a Trapezoidal Supercritical Flow Flume

Sizes and maximum discharge capacities for trapezoidal flumes vary widely. Some are capable of measuring flows under 28 ℓ/s (1 cfs), while one of the largest known to the writers (located near Tombstone, Arizona) has a throat width of 36.6m (120 ft) and is rated to a maximum discharge of 736,000 ℓ/s (26,000 cfs).

When the throat width is reduced to zero, such flumes are more properly termed triangular flumes. Distinct advantages of a triangular flume are its ability to measure accurately over a wide range of flows and its high tolerance for submergence. Some designs can tolerate submergences as high as 90%, as opposed to the 60% noted earlier for the Parshall flume. Trapezoidal flumes will lie between these two values depending on their individual geometries. Trapezoidal flumes, including triangular, are evaluated in Table 20.

Type HS, H, and HL Flumes - The U.S. Department of Agriculture (USDA) Soil Conservation Service has HS, H, and HL type flumes in use in many small watersheds. These USDA (40) flumes are illustrated in Figures 25 and 26. It is pointed out that all dimensions are proportional to the total depth (height) of a given flume. These flumes have the advantage of simple construction and reasonably good accuracy over a wide range of flows. A variety of sizes are available to measure flows ranging from 0.006 ℓ/s (0.0002 cfs) to 3,400 ℓ/s (120 cfs).

These flumes differ from the flume types discussed earlier because they are, in fact, more weir than flume. They are more properly termed open channel flow nozzles but are included here because of historical precedent. Their design attempts to combine the sensitivity and accuracy of the sharp-crested weir and the self-cleaning features of the flume. The result is a compromise in both. The flat, unobstructed bottom allows the passing of silt better than a weir. Like the weir, flow control is achieved by discharging through a sharp-edged opening. However, the flow is contracted gently from the sides only, much like the converging section of ordinary flumes. The plane of the exit tilts backward toward the incoming flow. Like weirs, these flumes should be used in free outfall situations, and the minimum head loss will be the measured head. Head is measured upstream in subcritical but accelerating flow, and critical flow occurs over the crest as with an ordinary weir.

These devices are capable of measuring quite wide ranges of flow in some instances. For example, Soil Conservation Service rating tables for H flumes indicate possible ranges of 175:1 for a 0.15m (0.5 ft) flume and 5633:1 for a 1.38m (4.5 ft) flume. Type HS, H, and HL flumes are evaluated as a group in Table 21.

Open Flow Nozzles

As mentioned in the discussion of Type HS, H, and HL flumes, the open (channel) flow nozzle is a combination of flume and sharp-crested weir.

TABLE 20. TRAPEZOIDAL FLUME EVALUATION

Evaluation Parameter		Scale		
1	Range	☐ Poor	☐ Fair	☒ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☐ Moderate	☒ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☒ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☐ Moderate	☒ Slight
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☒ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☐ Medium	☒ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☐ Medium	☒ Low
25	Portability	☒ No		☐ Yes

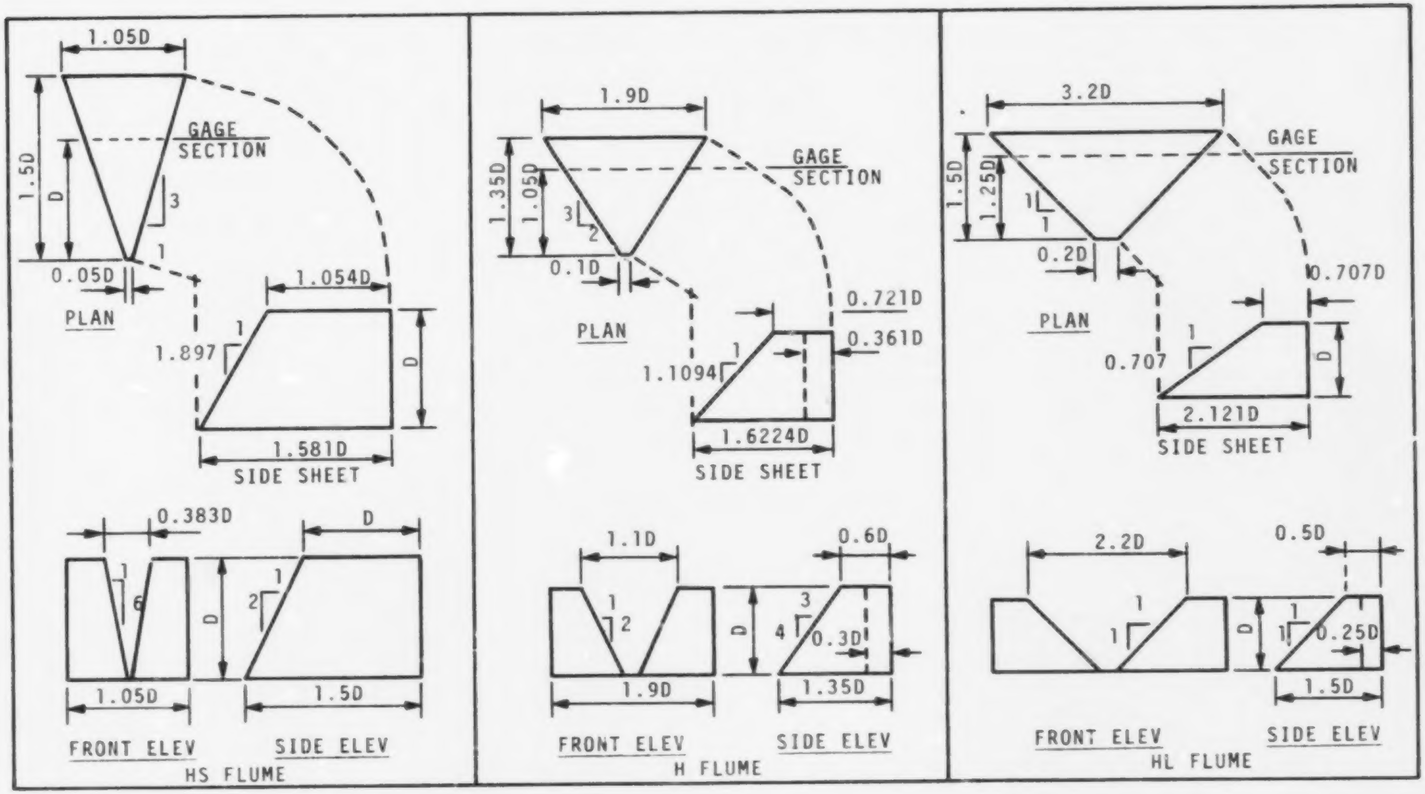
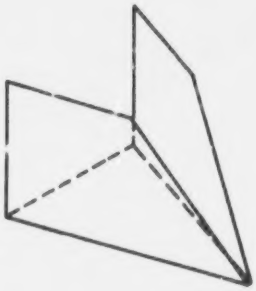
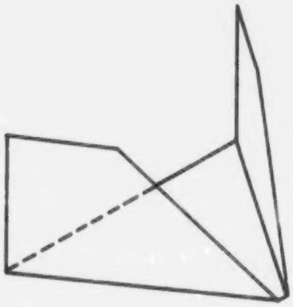

1.05D
1.5D
D
GAGE SECTION
3
1
0.05D
PLAN
1.054D
1
1.897
D
1.581D
SIDE SHEET
0.383D
1
6
D
1
2
1.05D
1.5D
FRONT ELEV
SIDE ELEV
HS FLUME
1.9D
1.35D
1.05D
3
2
0.1D
GAGE SECTION
PLAN
0.721D
0.361D
1
1.1094
1.6224D
SIDE SHEET
1.1D
1
2
1.9D
0.6D
D
3
4
0.3D
1.35D
FRONT ELEV
SIDE ELEV
H FLUME
3.2D
1.5D
1.25D
1
1
0.2D
GAGE SECTION
0.707D
PLAN
1
0.707
D
2.121D
SIDE SHEET
2.2D
1
1
0.5D
D
1
1
0.25D
1.5D
FRONT ELEV
SIDE ELEV
HL FLUME

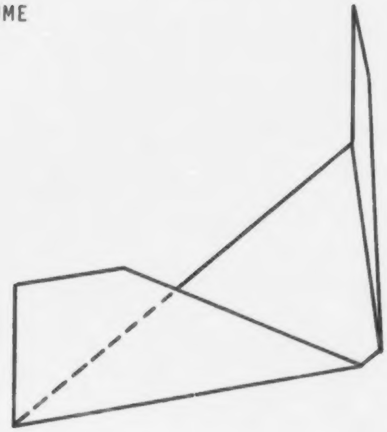
Figure 25. Type HS, H, and HL Flumes



HS FLUME



H FLUME



HL FLUME

Figure 26. Isometric View of Type HS, H, and HL Flumes

TABLE 21. TYPE HS, H, AND HL FLUME EVALUATION

Evaluation Parameter		Scale		
1	Range	☐ Poor	☐ Fair	☒ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☒ High	☐ Moderate	☐ Low
6	Effect of Solids Movement	☐ High	☒ Moderate	☐ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☒ High	☐ Medium	☐ Low
9	Manhole Operation	☐ Poor	☐ Fair	☒ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☒ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☒ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☒ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☒ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☐ Medium	☒ Low
25	Portability	☐ No		☒ Yes

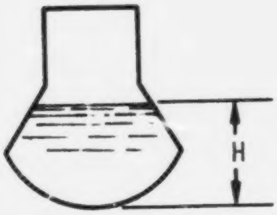
Unlike the conventional weir, it can handle suspended solids rather effectively, as a self-scouring action exists, and relatively large solids will pass without clogging. Use of open flow nozzles for heavy sludge, however, is not recommended unless calibration is for such use. Any deposition will alter the contour of the nozzle and, hence, its flow characteristics. For this reason the top of the nozzle is open in most designs to allow for ready inspection and cleaning.

Conversely, the open flow nozzle does not have the good head recovery characteristics of the flume. The loss of head through the device will be at least one pipe diameter. Open flow nozzles are designed to be attached to the end of a conduit flowing partially full and must discharge to a free fall.

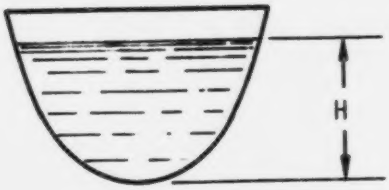
As with all head-area meters, the design is such that a predetermined relationship exists between the depth of the liquid within the nozzle and the rate of flow. In one design (the Kennison nozzle), the cross-section is shaped so that this relationship is linear. In another design (the parabolic nozzle), the relationship is a parabola so that each unit increase in flow produces a smaller incremental increase in head. The discharge profiles of these two nozzles are depicted in Figure 27.

Open flow nozzles are factory calibrated and offer reasonable accuracy (often better than ±5% of the reading) even under rather severe field conditions. Standard sizes are available from 15 to 91 cm (6 to 36 in.) in diameter, with maximum capacities up to 850 ℓ/s (30 cfs). These devices are capable of ranges of 20:1 or better and, for a given site, will exceed the range of either a Parshall flume or a sharp-crested weir. Parabolic nozzle lengths are roughly four times the diameter, while Kennison nozzle lengths are twice the diameter. Open flow nozzoles require a length of straight pipe immediately upstream of the nozzle, and the slope of the approach pipe must not exceed certain limits (depending upon nozzle size and profile) or else the calibration will be in error. Open flow nozzles are evaluated in Table 22.

The open flow nozzles discussed above were characterized by a cross-sectional profile shaped to give a better depth-discharge relationship than the ordinary circular pipe cross-section. The latter can be used for indicating flow, but high accuracies are not normally achieved, ±10% or worse being typical. The method, developed by Vanleer (41), is commonly referred to as the California pipe method, and uses as the primary device a straight, level (zero slope) section of pipe at least six diameters in length (see Figure 28a). The pipe, which cannot be flowing full, must be located so that there is free fall for the liquid at its exit, i.e., it must discharge freely into air. Also the velocity of approach must be at a minimum. The measurement taken is the distance from the crown of the pipe to the free water surface at the exit. An empirically-developed rating formula (or set of tables) is used, knowing



a. Linear (Kennison) Nozzle Profile ($Q \propto H$)

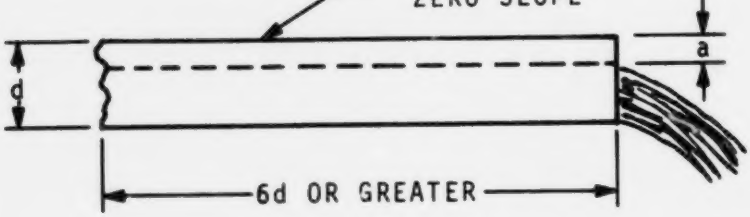


b. Parabolic Nozzle Profile ($Q \propto H^2$)

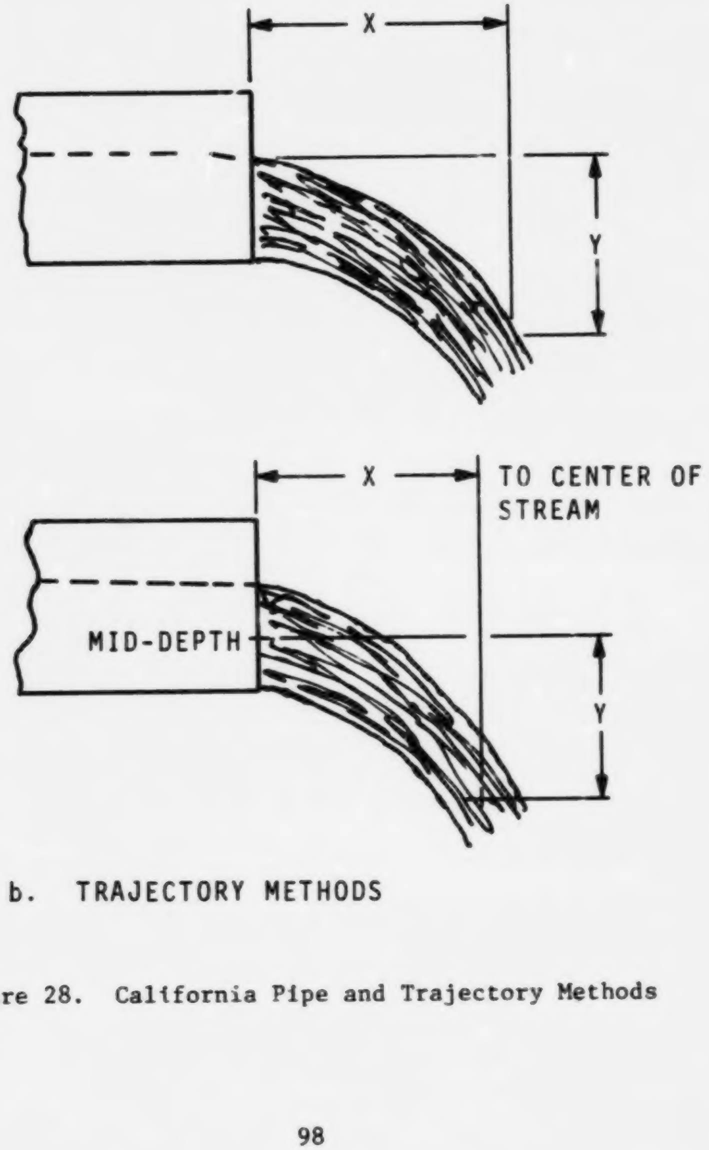
Figure 27. Open Flow Nozzle Discharge Profiles

TABLE 22. OPEN FLOW NOZZLE EVALUATION

Evaluation Parameter		Scale		
1	Range	☐ Poor	☐ Fair	☒ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☒ High	☐ Moderate	☐ Low
6	Effect of Solids Movement	☐ High	☒ Moderate	☐ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☒ High	☐ Medium	☐ Low
9	Manhole Operation	☐ Poor	☐ Fair	☒ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☒ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☒ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☒ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☒ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☐ Medium	☒ Low
25	Portability	☐ No		☒ Yes


ZERO SLOPE
a
d
6d OR GREATER

a. CALIFORNIA PIPE METHOD


X
Y
X
TO CENTER OF STREAM
MID-DEPTH
Y

b. TRAJECTORY METHODS

Figure 28. California Pipe and Trajectory Methods

the pipe diameter, to convert this distance (pipe diameter minus water depth at the exit) to discharge. The experimental data used to develop the formula were obtained on steel pipes from 7.6 to 25.4 cm (3 to 10 in.) in diameter, but tables can be found extending up to 0.9m (3 ft) diameter pipes. It has also been observed that, for depths greater than half the diameter, discharges do not necessarily follow the Vanleer formula. Except for its poorer accuracy, the California pipe method exhibits similar characteristics to the other open flow nozzles and, consequently, will not be separately evaluated.

Trajectory Methods

The California pipe method, although discussed under open flow nozzles, may also be considered as a trajectory method. Trajectory methods are not true head-area methods, but appear to fit in the discussion at this point. There are a number of techniques, both theoretically and empirically derived, but all share in common the taking of two measurements, one in the vertical (Y) and one in the line of the pipe axis (X) as indicated in Figure 28b. Like the California pipe method they should be viewed as methods for producing flow estimates rather than accurate measurements. The theoretically based methods generally ignore resistance effects and thereby arrive at a parabolic contour for the center line issuing stream. These measurements, as indicated in the second sketch of Figure 28b, should preferably be used when applying theoretical methods as opposed to those indicated in the first sketch of Figure 28b, but field conditions and operator experience play a much greater role in improving the discharge estimate.

When the mid-depth value of Y has been set at one foot (Figure 28b) and the pipe is horizontal but not flowing full, the discharge in gallons per minute is approximated by 1,800 times the product of the cross-sectional area of the issuing stream and the value of X measured in feet. Other empirically developed coordinate or trajectory methods (e.g., the Purdue method) have been put forth over the years in the form of equations, tables, and curves, but little comparative work has been performed. Because of the lack of accuracy of such techniques and the infrequent occurrence of suitable freely discharging pipes in storm and combined sewers, trajectory and other free overfall methods will not be evaluated or discussed further.

FLOW VELOCITY

The flow rate of a stream can be expressed as the product of the mean flow velocity across a cross-section and the flow area at that point. In open channel flow, this will generally require two separate measurements, one to determine mean velocity and the other to determine flow depth. Under pressurized flow conditions, the conduit cross-section is the area, and only the velocity need be measured. A complication in this seemingly simple procedure is that the velocity profile of a flow is dependent upon many factors, and frequently a series of velocity measurements will be necessary in order to arrive at the average velocity across a section. The following quotation from the USDI Bureau of Reclamation (10) is given to illustrate some of the vagaries and methods for implementation: "The following methods are used to determine mean velocities in a vertical line with a current meter:

(1) Two-point method.
(2) Six-tenths-depth method.
(3) Vertical velocity-curve method.
(4) Subsurface method.
(5) Integration method.
(6) Two-tenths method.
(7) Three-point method.
(8) One-point continuous method.

The two-point method consists of measuring the velocity at 0.2 and then at 0.8 of the depth from the water surface, and using the average of the two measurements. The accuracy obtainable with this method is high and its use is recommended. The method should not be used where the depth is less than 2 feet.

The six-tenths-depth method consists of measuring the velocity at 0.6 of the depth from the water surface, and is generally used for shallow flows where the two-point method is not applicable. The method gives fairly satisfactory results.

The vertical velocity-curve method consists of measuring the velocities at equal vertical intervals of 0.5 foot or more and calculating their arithmetical mean, or finding the mean value from a curve obtained by plotting the measurements on cross-section paper. The method is very accurate, but is time consuming and costly.

The subsurface method involves measuring the velocity near the water surface and then multiplying it by a coefficient ranging from 0.85 to 0.95, depending on the depth of water, the velocity, and the nature of the stream or canal bed. The difficulty of determining the exact coefficient limits the usefulness and accuracy of this method.

The integration method is performed by observing the velocity along a vertical line by slowly and uniformly lowering and raising the meter throughout the range of water depth two or more times. The method is not accurate and should be used only for comparisons or quick rough checks.

The two-tenths, three-point, and one-point continuous methods are special procedures based on a relationship - previously established for the section - between the true discharge and the velocities observed by these methods. These methods are generally reliable for sections which undergo no serious changes because of erosion, sedimentation, or other deformation."

For conduits flowing full and under pressure, the velocity profile will be a function of the Reynolds number, the cross-sectional shape, and the wall roughness, among other factors. As in the case for open channel flow, some prior knowledge of the flow characteristics is necessary in order to use a single velocity reading to compute discharge.

In the following discussion it is generally assumed that such knowledge exists, having been obtained by calibration (or other measurements) at the site or from other empirical work. Methods for measuring the stage for determining flow area in open channel flow are also assumed and will not be addressed here. It is common practice to refer to devices in this category as velocity meters when they are normally applied to pressurized flow and as current meters when they are normally applied to open channel flow, but no real distinction should be attached to the terms. A good review of velocity measuring devices has been recently prepared by Smoot (42), and liberal use has been made of some of his comments in the following paragraphs.

Floats

In the float method of determining flow velocity, one or more floats are placed in the stream and their time to travel a measured distance is determined. The simple use of surface floats, floats immersed less than one fourth of the flow depth, is the least desirable of all as they may be subjected to wind effects in addition to current effects. Since the surface velocity is greater than the mean velocity, a correction must be applied. For reasonably smooth flows in regular conduits, the correction factors range from around 0.7 to 0.9 depending upon flow depth, conduit shape, and other factors.

Another method makes use of oranges, which float mostly submerged and work fairly well in the shallow flows found in many sewers. Somewhat more sophisticated are the rod floats, which consist of a square or round rod (usually wooden); the rod is designed with a weighted end so that it will float in a vertical position with the length of the immersed portion approximately 0.9 times the depth of the flow. The reasoning here is that the velocity of a rod float which extends from the water surface almost to the bottom will be very nearly the same as the mean velocity of the flow.

A further improvement in accuracy is known as the integrating float method, which is discussed by Lin (43). Here, buoyant spheres are released from the channel floor and are displaced downstream as they rise to the surface. The time from the moment of release to the moment of surfacing is measured as is the distance traveled downstream. The proper selection of size and specific gravity of the spheres for a particular flow depth minimizes the error caused by initial ascent acceleration and permits a flow measurement method that automatically compensates for velocity distributions in a channel. The method is best suited for fairly low velocities.

These methods should only be used for making rough estimates and are not well suited for many storm or combined sewer applications, especially the integrating floats. They are evaluated in Table 23.

Tracers

In an attempt to improve upon the accuracy of float velocity methods, many investigators turned to the use of liquid tracers to measure velocity. Dye, salt, and radioactive tracer substances have been used. In principle, a slug of tracer is instantaneously introduced into the flow at an upstream station, and the time of travel to a downstream station a known distance away is measured. The technique should not be confused with dilution techniques which will be discussed later.

When dyes are used, the technique is sometimes referred to as the color-velocity method. Potassium permanganate, fluorescein, uranine, sodium dichromate, and rhodamine dyes have been commonly used. In application, the downstream time should be noted when the center of the mass of colored liquid passes. Considerable judgment is required to determine the center of mass of the dye pattern and, consequently, the accuracy of timing is limited. In actuality, the peak concentration is often used. In high velocity flows, air entrained near the surface and spray above the surface can further degrade the measurement. Also, it may be uncertain whether the observed dyecloud velocity is the mean velocity of the stream or just the velocity of the surface. Careful use of a fluorometer can help eliminate part of the uncertainties, but high accuracies should not be expected as a rule.

A more precise method uses salt as the tracer and is often referred to as the Allen salt velocity method. It is based on the fact that salt in solution increases the electrical conductivity of water. In application, a quantity of salt solution is forced into the stream under pressure through quick-closing valves. In determining the average velocity of the salt solution, two pairs of electrodes are installed in the stream a known distance apart. The electrodes are energized by an electrical current, and the resistivity of the water path is measured. The greater conductivity of the salt solution will appear as a decrease in resistance and, hence, an increase in current flow. If the electrodes are connected to a control recording galvanometer, the graph of

TABLE 23. FLOAT VELOCITY EVALUATION

	Evaluation Parameter	Scale		
1	Range	☐ Poor	☐ Fair	☒ Good
2	Accuracy	☒ Poor	☐ Fair	☐ Good
3	Flow Effects on Accuracy	☒ High	☐ Moderate	☐ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☐ Moderate	☒ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☐ Fair	☒ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☐ Moderate	☒ Slight
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☒ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☒ No		☐ Yes
15	Maintenance Requirements	☐ High	☐ Medium	☒ Low
16	Adverse Ambient Effects	☒ High	☐ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☒ No		☐ Yes
20	Precalibration	☐ No		☐ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☐ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☐ Medium	☒ Low
25	Portability	☐ No		☒ Yes

current strength will have two humps that indicate the passing of the salt slug past each pair of electrodes. The distance on the chart between these two humps (or peaks) is a measure of the time of travel, and from this and the electrode spacing the flow velocity can be obtained. Salt-velocity methods are more amenable to automation than color-velocity methods. However, this requires rather special equipment not familiar to average personnel, and its use is relatively expensive. With care, accuracies of better than ±2% can be achieved. This method is sometimes used to calibrate other flow measurement devices in place.

Radioisotopes can also be used as velocity tracers much as in the salt-velocity method. The sensors here are scintillation counters or geiger counters, but the application is essentially as described above. The requirements for Federal licensing, expensive equipment, and highly trained personnel together with the reluctance on the part of the public to accept deliberate introduction of radioactive substances into their water tend to limit the application of this technique. Tracer velocity methods as a group are evaluated in Table 24.

Vortex

There are two major sub-types of vortex meters, the difference being in whether vortex rotation or vortex generation is measured.

Vortex-Velocity - The vortex-velocity meter has been discussed by Henke (44) and McVeigh (45). It is designed to be used in pipes flowing full and under pressure. Essentially the meter is a conduit having a bulge on one side. Flow through the conduit results in a vortex pool in the enlarged section of the conduit. A vortex cage located in the pool counts its revolutions, which are related to the flow velocity. These meters can be quite accurate (to ±0.5% of the reading) in certain flows and have a usual rangeability of around 10:1. They are sensitive and have very low pressure loss. However, solids in the flow and potential fouling problems make the device appear generally unsuitable for sewage applications. Vortex-velocity meters are evaluated in Table 25.

Closely related to the operating principle of the vortex-velocity meter is a rotorless current meter developed in Russia. As described by Replogle (8): "*The meter consists of a tube which is shaped into a closed, race-track-shaped oval with two parallel lengths. In one of the straight lengths, several slots parallel to the axis are cut through the tube. A ball whose density is equal to that of the gaged fluid is enclosed in the tube. The meter is placed in the stream so that the direction of the slots coincides with the direction of the current. The fluid in the tube is set in motion by the viscous force transmitted through the slots, and the ball moves around the closed oval at a rate depending on the stream velocity. Advantages claimed for the meter are*

TABLE 24. TRACER VELOCITY EVALUATION

Evaluation Parameter		Scale		
1	Range	☐ Poor	☒ Fair	☐ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☒ Moderate	☐ Slight
4	Gravity & Pressurized Flow Operation	☐ No		☒ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☐ Moderate	☒ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☐ Fair	☒ Good
10	Power Requirements	☐ High	☒ Medium	☐ Low
11	Site Requirements	☐ High	☐ Moderate	☒ Slight
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☒ Slight
13	Simplicity and Reliability	☐ Poor	☒ Fair	☐ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☒ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☐ Moderate	☒ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☒ Fair	☐ Good
19	Self Contained	☒ No		☐ Yes
20	Precalibration	☒ No		☐ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☒ High	☐ Medium	☐ Low
25	Portability	☐ No		☒ Yes

TABLE 25. VORTEX-VELOCITY METER EVALUATION

Evaluation Parameter		Scale		
1	Range	☒ Poor	☐ Fair	☐ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☒ High	☐ Moderate	☐ Slight
7	Flow Obstruction	☒ High	☐ Moderate	☐ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☒ Poor	☐ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☒ High	☐ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☒ High	☐ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☒ Fair	☐ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☒ High	☐ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☐ Moderate	☒ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☒ Poor	☐ Fair	☐ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☒ Fair	☐ Good
22	Maintenance of Calibration	☐ Poor	☒ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☒ High	☐ Medium	☐ Low
25	Portability	☒ No		☐ Yes

simplicity, low cost, light weight, and ability to operate at low velocities and depths as small as one inch." Such a device would not seem well suited for dirty flows such as sewage because of fouling problems.

Eddy-Shedding - In these devices, which can be used in open channel as well as pressurized flow, the measure is the count of the frequency of the vortex street formed behind a strut in the flow. This phenomenon is well treated by Schlitchting (46). This shedding frequency is directly proportional to the flow velocity and the Strouhal number and inversely proportional to the diameter of the strut. Typical lower threshold values are around 0.03 to 0.06 m/s (0.1 to 0.2 fps). Various means of detecting the eddies have been tried, including acoustic sensors and pressure transducers downstream from the strut and a variable reluctance transducer attached to the strut to measure its vibration. Problems have been met, many of them doubtless arising from the complications in the uniform pattern of the eddies caused by natural turbulence in the flow. Of course, any collection of debris on the strut will cause serious errors. Accuracies as high as ±1% have been achieved under ideal conditions, and ranges of 50:1 are commonplace. Eddy-shedding meters are evaluated in Table 26.

Turbine Meters

The turbine meter uses a turbine (which rotates about a horizontal axis) with many small blades of slight curvature to measure flow velocity. The turbine meter, discussed by Artz (47) and Yard (48), is probably available in more variations than any other mechanical meter. They are chiefly used in measuring flows in pipes that are flowing full and under pressure. Turbine meters can be quite accurate (±0.5% of reading) if properly calibrated, and their repeatability is often better than ±0.1%. Linear operation over a 15:1 range is not uncommon. There is some pressure loss associated with turbine meters, and they are not well suited for liquids containing suspended solids, entrained air, or trash and debris. Turbine meters are evaluated in Table 27.

Rotating-Element Meters

Essential features of these meters are a wheel (primary device), which rotates when immersed in the flow, and a provision (secondary device) for determining either the number of turns of the wheel or its rate of rotation. Rotating-element flowmeters may be grouped into one of two sub-types, depending upon whether their axis of rotation is horizontal or vertical. Some writers refer to them as propeller meters (horizontal-axis) or cup-type meters (vertical-axis). Strictly speaking, the turbine meter would fall in the horizontal-axis class but, because of its greater limitations, it was addressed separately. There has been a long-standing debate on which of the two classes of rotating-element current meters is better, and the issue will not be belabored here.

TABLE 26. EDDY-SHEDDING METER EVALUATION

Evaluation Parameter		Scale		
1	Range	☐ Poor	☒ Fair	☐ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☐ No		☒ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☒ Moderate	☐ Slight
7	Flow Obstruction	☐ High	☒ Moderate	☐ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☐ Fair	☒ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☐ Moderate	☒ Slight
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☒ Slight
13	Simplicity and Reliability	☐ Poor	☒ Fair	☐ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☒ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☐ Moderate	☒ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☒ Fair	☐ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☒ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☒ Medium	☐ Low
25	Portability	☐ No		☒ Yes

TABLE 27. TURBINE METER EVALUATION

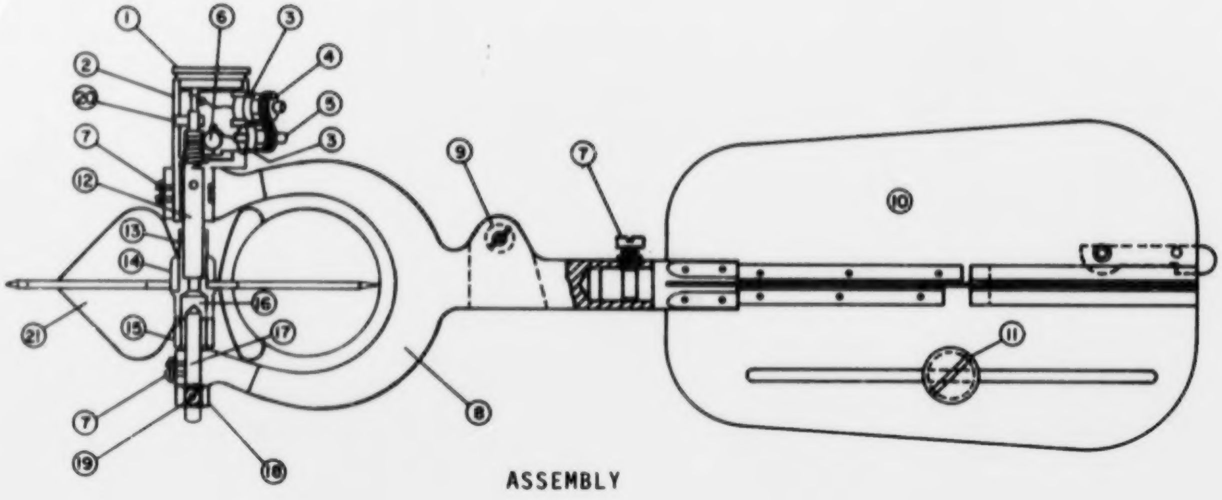
Evaluation Parameter		Scale		
1	Range	☒ Poor	☐ Fair	☐ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☒ High	☐ Moderate	☐ Slight
7	Flow Obstruction	☒ High	☐ Moderate	☐ Slight
8	Head Loss	☐ High	☒ Medium	☐ Low
9	Manhole Operation	☒ Poor	☐ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☒ High	☐ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☒ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☒ Fair	☐ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☒ High	☐ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☐ Moderate	☒ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☒ Fair	☐ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☒ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☒ High	☐ Medium	☐ Low
25	Portability	☒ No		☐ Yes

Both have proper applications with both advantages and disadvantages. Horizontal-axis meters have found wide use in pipe lines, water mains, and high-flow applications that require a low permanent pressure drop. They can handle higher flow rates than volumetric (positive displacement) flowmeters, but not as high as turbine meters. Along with vertical-axis meters, they are also used to measure open channel flows. A thorough treatment of the use of current meters for open channel flow measurement is given by Buchanan and Somers (49) and the USDI Bureau of Reclamation (10).

Vertical-Axis Meters - The most common vertical-axis meters are those with either the S-shaped (or Savonius) rotor or with a bucket wheel made up of a number of conical or hemispherical cups. In general, the bearing systems in the vertical-axis meters are simpler in design, more rugged, better protected from silty water, and consequently, easier to maintain than those of horizontal-axis meters. Bearing adjustment is usually less sensitive, and their calibration at lower velocities (where frictional effects are higher) is more stable. Vertical-axis meters operate in lower velocities than horizontal-axis meters, generally having lower threshold velocities of around 0.03 meters per second (0.1 fps) or less. Finally, a single cup rotor serves for the entire range of velocities, and the rotor is repairable in the field without adversely affecting the rating.

The type AA Price current meter is probably the most common type of vertical-axis meter. This device has a rotor 12.7 cm (5 in.) in diameter and 5 cm (2 in.) high with six cone-shaped cups mounted on a stainless steel shaft. It also has a vane to keep the rotor headed into the flow, an electrical device to signal the number of revolutions, and provisions for handling the meter. An assembly drawing of a Price type AA current meter is given in Figure 29. There is also a Price type BTA current meter which differs from the type AA only in its mounting yoke, contact chamber, and the absence of the tailpiece. For smaller flows there is a pygmy meter that is similar to the Price meter but only about two-fifths its size. The rotational speed of the pygmy rotor is more than twice that of the Price meters, and consequently its use is limited to velocities up to 0.9 or 1.2 m/s (3 or 4 fps).

Horizontal-axis meters - This class of current meter is less sensitive to vertical velocity components than is the vertical-axis meter, which will over-register in most such instances. Vertical-axis meters cannot correct for oblique flow, whereas some of the helical rotors of horizontal-axis meters are designed to act as nearly perfect cosine meters. The horizontal-axis rotor disturbs the flow less because of its axial symmetry with flow direction. They also present a clearer view to the flow than vertical-axis meters and, consequently, are slightly less susceptible to fouling. Bearing friction, especially at higher velocities, is less than for vertical-axis meters because bending



LIST OF PARTS

1. CAP FOR CONTACT CHAMBER
2. CONTACT CHAMBER
3. INSULATING BUSHING FOR CONTACT BINDING POST
4. SINGLE-CONTACT BINDING POST
5. PENTA-CONTACT BINDING POST
6. PENTA GEAR
7. SET SCREWS
8. YOKE
9. HOLE FOR HANGER SCREW
10. TAILPIECE
11. BALANCE WEIGHT
12. SHAFT
13. BUCKET-WHEEL HUB
14. BUCKET-WHEEL HUB NUT
15. RAISING NUT
16. PIVOT BEARING
17. PIVOT
18. PIVOT ADJUSTING NUT
19. KEEPER SCREW FOR PIVOT ADJUSTING NUT
20. BEARING LUG
21. BUCKET WHEEL

Figure 29. Assembly Drawing of a Price Type AA Current Meter

moments on the shaft are eliminated. Finally, although the horizontal-axis meter has a higher velocity threshold of around 0.08 m/s (0.25 fps), it is capable of measuring higher flow velocities, with some designs capable of measuring in excess of 9 m/s (30 fps).

The types of horizontal-axis meters in common use today are the Ott, Neyrpic (Dumas), Haskell, and Hoff. The Ott meter was developed in Germany, the Neyrpic meter in France, and the Haskell and Hoff in the United States. All are precision instruments that can cover a wide range of flow velocities by using propellers with a variety of screw pitches.

Townsend and Blust (50) give a comparison of stream velocity meters, and the reader who is further interested is referred to their discussion. No rotating-element current meter is ideal for any extended period of unattended operation, but they can be used to give excellent results in the hands of a skilled operator. Generally they are inexpensive, simple in design, and rugged in construction. A major shortcoming of all rotating-element current meters is that their accuracy is so closely coupled with the operator. In general, it requires much experience and great care to select gaging sites and apply techniques in such a way as to obtain results that approach the basic accuracy of the instrument itself (often ±1%). Typically, it is difficult to achieve better than ±2 or 3% accuracy in the field. Carter and Anderson (51) and Smoot and Novak (52) discuss accuracy of current meter measurements further. Their obstruction to the flow and susceptibility to fouling limit their use in storm and combined sewers. Rotating-element velocity meters are evaluated in Table 28.

Other Devices

Other devices are available to measure the velocity of open channel flow at a point within the stream. They include pitot tube, electromagnetic, venturi, thermal, optical, and other fundamental principles. They are discussed in the subsections of this report that address their particular principles of operation, and will not be covered again here. In this use (as current meters) they all require attended operation. Otherwise they function as described in their individual discussions.

FORCE-DISPLACEMENT

This class of flowmeters is related to the variable area class discussed earlier in that both operate by a force due to the flow displacing an obstruction (primary element) that is immersed in the fluid. In effect, the drag of the obstruction is being measured, and this is related to the square of the fluid velocity, among other parameters which include the drag coefficient. Being proportional to the velocity squared means that force-displacement meters will tend to be insensitive at very low

TABLE 28. ROTATING-ELEMENT METER EVALUATION

Evaluation Parameter		Scale		
1	Range	☐ Poor	☒ Fair	☐ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☐ No		☒ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☒ High	☐ Moderate	☐ Slight
7	Flow Obstruction	☐ High	☒ Moderate	☐ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☒ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☐ Moderate	☒ Slight
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☒ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☒ No		☐ Yes
15	Maintenance Requirements	☒ High	☐ Medium	☐ Low
16	Adverse Ambient Effects	☒ High	☐ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☒ No		☐ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☐ Medium	☒ Low
25	Portability	☐ No		☒ Yes

velocities. The dependency on drag coefficient means that calibration will shift if the primary element becomes fouled by buildup or debris. The secondary device measures the displacement of the primary element and converts this into velocity or actual discharge.

Vane Meters

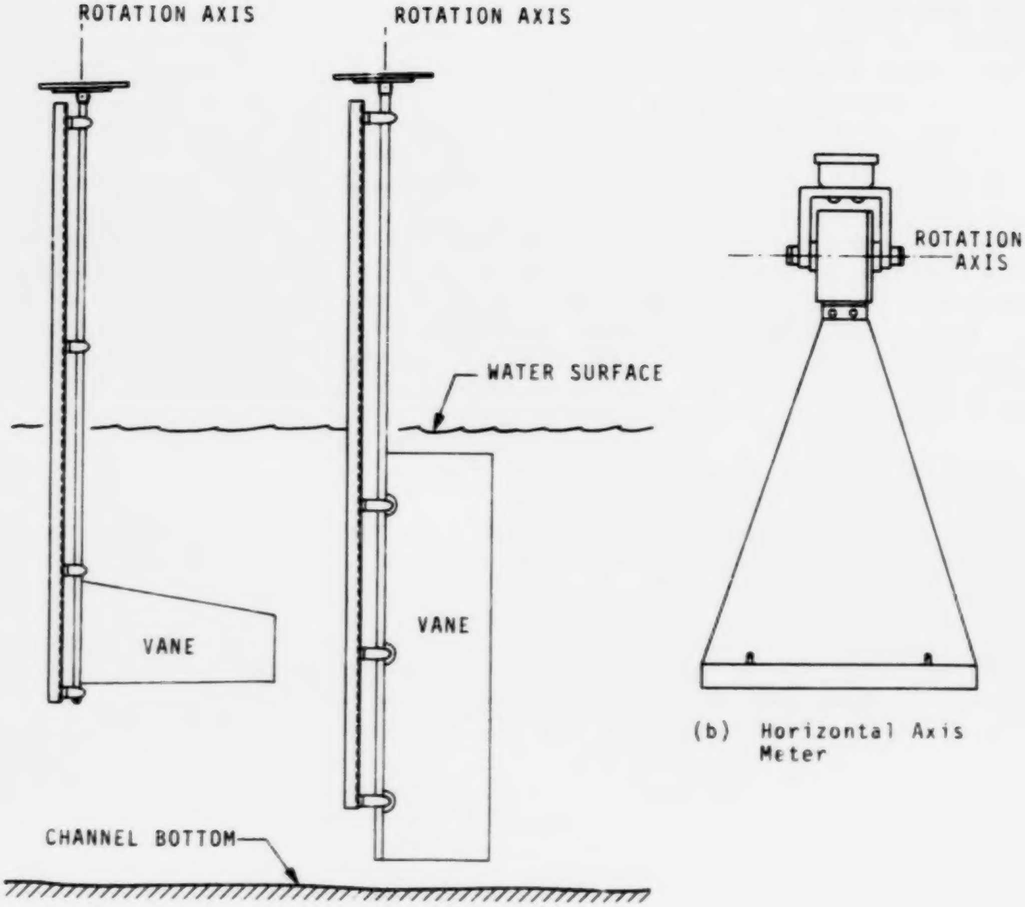
The vane meter is simply a vane hinged along either a vertical or horizontal axis and placed in the flow (Figure 30). The flowing fluid produces an angular displacement which is related to velocity and read by the secondary element.

The vertical-axis vane meter is one of the most common. As indicated in Figure 30a, the vane may be quite short as compared with the flow depth or, for flows whose levels do not change greatly, the vane may extend over almost the entire flow depth in an attempt to average the velocity. The advantages of the vertical axis arrangement are that the counterbalancing weight can be easily changed to alter flow ranges; it can be made to integrate velocities over a great portion of the vertical; and its mechanical output can be recorded and indicated visually. Its disadvantages include its tendency to collect debris; the high degree of bearing friction (resulting from its typically heavy weight) that adds to the low flow insensitivity problem of this class; and the fact that removal for service or repair is difficult.

The horizontal-axis vane meter (see Figure 30b) overcomes many of the disadvantages of the vertical-axis type. Among its advantages are the ease of changing the weight at the bottom in order to change ranges; its capability for being installed totally submerged to avoid fouling by floating debris; its light weight and simplified design to reduce bearing friction; and the fact that its output is usually electrical. On the other hand, despite its relatively small size and weight, it may not be convenient for some installations, and there is no visual readout of deflection. Both types of vane meters will be affected by wind on the exposed portion of the vane.

Robinson (53) has described a somewhat different form of the horizontal-axis vane meter that is sometimes referred to as the pendvane meter. It is designed for use in open channel flow, usually for small channels less than 0.9m (3 ft) deep and 1.8m (6 ft) wide. In the pendvane meter, the vane is shaped to match a particular channel cross-section so that its displacement is the same for a particular discharge rate irrespective of the velocity profile (within certain specified depth limits). Thus the pendvane meter indicates discharge rate directly. Errors of ±10% are possible, and flow range is low.

Two percent might be considered an accuracy limit for vane meters and accuracies of ±5% or more should be considered more typical. For a


ROTATION AXIS
ROTATION AXIS
ROTATION AXIS
WATER SURFACE
VANE
VANE
CHANNEL BOTTOM

(a) Vertical Axis Meters

(b) Horizontal Axis Meter

Figure 30. Vane Meters

given weight (i.e., range setting), 5:1 or so should be considered a typical flow range that these devices can handle. Vane meters are evaluated in Table 29.

Hydrometric Pendulum

The hydrometric pendulum is sometimes used in open channels as a current meter. In its most elemental form, it consists of a ball (heavier than the fluid) suspended by a string (or light cable). The angular deflection of the ball and string is proportional to the flow velocity in the vicinity of the ball. Accuracies are poor because stream fluctuations make determination of the deflection angle difficult. These are partly due to the vortex shedding phenomenon discussed earlier. Also, there is usually no method for recording the output, and the device must be manually operated. Accuracy is further degraded by the complex and somewhat uncertain corrections for drag on the line that are required. Drag on the line is increased greatly by floating debris, such as moss or grass, catching on it. Good features are that the drag element can be very easily changed to alter the ranges, and the line can easily be lengthened or shortened to measure velocity at various depths. The hydrometric pendulum is evaluated in Table 30.

Target Meter

The target meter, discussed by Stapler (54), is a more sophisticated force-displacement device for measuring flows. The primary element (or target) is shaped similarly to the sharp-edged annular orifice. It mounts on a support that passes through the conduit wall via a sealed, flexible closure, and the displacement of the primary device is measured by a strain gage or some other suitable displacement measuring secondary device (Figure 31). This meter has relatively high accuracies, approaching those of the orifice meter under certain conditions.

Strictly speaking, although the target meter is a point velocity measuring device, the point may be rather large so that an integrating effect is achieved. Replogle (55) reports that analytical and experimental studies have indicated that target meters can be designed for open channels of any cross-sectional shape and can indicate discharge rate directly to better than ±3%, independent of flow depth. Such meters are limited in discharge measurement primarily by the ability to predict the general type of velocity profile existing in the flow. Typical ranges are around 5:1. They do not appear especially suitable for use in flows containing suspended material such as sewage. Target meters are evaluated in Table 31.

Other

Brief mention will be made here of a few other force-displacement type flowmeters. They do not appear well suited for storm or combined sewer flow measurement at this time, but are included since special adaptations may be possible in some situations.

TABLE 29. VANE DEFLECTION METER EVALUATION

Evaluation Parameter		Scale		
1	Range	☒ Poor	☐ Fair	☐ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☒ Moderate	☐ Slight
7	Flow Obstruction	☒ High	☐ Moderate	☐ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☒ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☐ Moderate	☒ Slight
12	Installation Restrictions or Limitations	☐ High	☒ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☒ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☒ Fair	☐ Good
22	Maintenance of Calibration	☐ Poor	☒ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☐ Medium	☒ Low
25	Portability	☒ No		☐ Yes

TABLE 30. HYDROMETRIC PENDULUM EVALUATION

Evaluation Parameter		Scale		
1	Range	☒ Poor	☐ Fair	☐ Good
2	Accuracy	☒ Poor	☐ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☒ Moderate	☐ Slight
7	Flow Obstruction	☐ High	☒ Moderate	☐ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☐ Fair	☒ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☐ Moderate	☒ Slight
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☒ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☒ No		☐ Yes
15	Maintenance Requirements	☐ High	☐ Medium	☒ Low
16	Adverse Ambient Effects	☒ High	☐ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☒ No		☐ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☒ Fair	☐ Good
22	Maintenance of Calibration	☐ Poor	☒ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☐ Medium	☒ Low
25	Portability	☐ No		☒ Yes

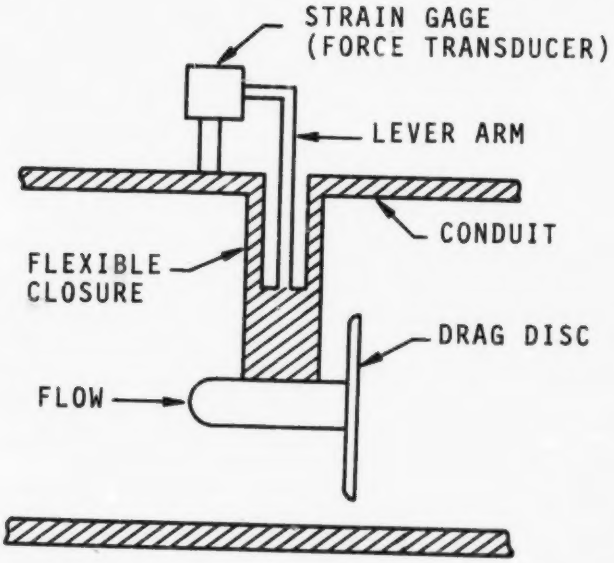

STRAIN GAGE
(FORCE TRANSDUCER)
LEVER ARM
CONDUIT
FLEXIBLE CLOSURE
DRAG DISC
FLOW

Figure 31. Target Meter

TABLE 31. TARGET METER EVALUATION

	Evaluation Parameter	Scale		
1	Range	☒ Poor	☐ Fair	☐ Good
2	Accuracy	☐ Poor	☒ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☒ Moderate	☐ Slight
7	Flow Obstruction	☒ High	☐ Moderate	☐ Slight
8	Head Loss	☐ High	☒ Medium	☐ Low
9	Manhole Operation	☒ Poor	☐ Fair	☐ Good
10	Power Requirements	☐ High	☒ Medium	☐ Low
11	Site Requirements	☐ High	☐ Moderate	☒ Slight
12	Installation Restrictions or Limitations	☐ High	☒ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☒ Fair	☐ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☒ High	☐ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☐ Moderate	☒ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☒ Poor	☐ Fair	☐ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☒ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☒ High	☐ Medium	☐ Low
25	Portability	☒ No		☐ Yes

The jet deflection meter is a development reported by Stanney (56) in which a fluid jet is directed across the flow stream towards two impact tubes on the opposite side. The flow stream displaces the jet an amount proportional to the flow rate, thereby creating a differential pressure between the two impact tubes that is a linear function of the flow velocity of the measured fluid. Like many so-called fluidic devices for measuring flow, it is primarily suitable for gas flows. It has been used for clean water flow velocities from 0.03 to 0.3 m/s (0.1 to 1 fps). Accuracies of ±1% have been obtained over flow ranges of 5:1. The device does not appear at all suitable for dirty liquids and, consequently, will not be discussed further.

The ball and tube flowmeter consists of a tube (usually transparent) bent through 180 degrees into some shape of an arc, semicircular being the original design. The tube is placed in a vertical plane concave upward, and a ball (primary element) of density greater than the liquid and diameter smaller than the tube is placed inside. The flow creates drag forces on the ball, and it rises in the tube until they are balanced by the gravity forces; thus, the position of the ball along the tube is a measure of the flow rate. The device should not be confused with the rotameter which uses a taper so that the area varies as the float is displaced. Of course, ball and tube flowmeters are only suitable for pressurized flow. They are not obtainable commercially (to the writers' knowledge), but can be easily fabricated in the laboratory. Accuracies of around ±2-5% can be achieved over flow ranges of up to 5:1. When maximum design flow rates have been appreciably exceeded, the ball will be lost unless provision is made for capturing it at some point.

Another interesting force-displacement type of flowmeter utilizes a variable weight principle. It consists of a vertical section of pipe (usually transparent) containing a float of density slightly less than that of the fluid to be measured. A chain is fastened to the bottom of the float. The device operates under pressurized flow conditions with flow in the upward direction. As the flow rate increases, the float rises and in so doing picks up a larger portion of the chain, thus effectively varying its weight. The height of the float in the tube is a measure of the flow rate. This device is also not commercially available to the writers' knowledge.

FORCE - MOMENTUM

Force-momentum flowmeters measure the mass flow rate of the fluid as opposed to its volumetric flow rate. Several instruments for which the measured variable is directly related to mass flow will be discussed below. Those that add mechanical energy to the system, such as the transverse momentum devices, generally require a constant speed drive and rotating seals.

Axial Flow Mass Meter

The axial flow mass meter uses a turbine driven at constant speed to induce a constant angular velocity to the fluid and a complementary spring-retained rotor to measure the force required to overcome the angular momentum. The angular displacement of the retained rotor is directly related to the mass flow of the fluid. The axial-flow, transverse-momentum device is the most common of this type and is available in several configurations. They can be quite accurate (±0.5% of reading) over ranges, typically, of 10:1. They clearly are suited only for pressurized flows and clean fluids.

Radial Mass Meter

This device, often referred to as a Coriolis mass flowmeter, has a primary element resembling a centrifugal pump. The fluid is accelerated radially, and the torque required to accomplish this is proportional to the mass flow of the fluid. These devices have been discussed by Halsell (57). They produce a pressure rise, rather than drop, and have been successfully used with liquids, foams, and slurries. Accuracies of ±1% over of 10:1 range have been achieved.

Gyroscopic Mass Meter

This meter consists of a circular pipe loop, the fluid flowing through it constituting a gyroscope. If a gyroscope is rotated about a perpendicular axis, a torque is created due to precession effects. Like the other mass flowmeters, a constant-speed motor and rotating seals are required (in one design the gyro is vibrated rather than rotated, and flexible couplings replace the rotating seals). The meter is an unobstructed pipe so it is suitable for handling troublesome liquids and flows high in solids. Pressure losses are low, but external power is required and the meter is quite expensive. Its range and accuracy are similar to the other mass meters.

Magnus Effect Mass Meters

The Magnus effect, discussed by Schlitchting (46) and others, is the phenomenon that produces a differential force on a body spinning in a flow field. (It allows golfers to slice and baseball pitchers to throw curves, for example.) The force is proportional to the fluid velocity and density and to the surface speed of the rotating body among other factors. In the Magnus-effect mass meter, a rotating cylinder is immersed with its axis at right angles to the flowing stream. Since the cross-section of the conduit and the surface speed of the cylinder are constant, the mass flow is a direct function of the "lift" on the cylinder, which is measured with suitable transducers. Again, the meter requires a constant speed drive and rotating seals. The spinning cylinder poses a rather severe flow obstruction, and the device is not suitable for dirty flows.

Force-momentum meters as a group are evaluated in Table 32.

THERMAL

Thermal flowmeters were originally developed for the measurement of gas flows but have also found application in liquid flows in recent times. In view of the extremely rapid response times that are achievable with some designs, they have been especially useful in the study of turbulent boundary layer structures and the like. Fundamentally, they all work on the principle that heat transferred between a body and a flowing stream is related to the rate of flow.

Hot Tip Meters

When an electrically heated (bead, wire, film, etc.) is placed in a flowing fluid, heat will be transferred from the element to the fluid at a rate that is a function of: (a) the velocity of the flow; (b) the temperature, density, viscosity, and thermal conductivity of the fluid; and (c) the temperature, geometry, and properties of the element. If all but one of the fluid-flow and element variables are kept constant, the heated element is a transducer for measuring the remaining variable. A few typical hot-tip element configurations are depicted in Figure 32.

Two methods are used in flow measurement. The first technique employs a constant current passing through the sensing element. Variation in flow results in changed element temperature; hence, changed resistance, which thereby becomes a measure of flow. The major drawback of the constant current system is that the frequency response of a sensor depends not only on sensor characteristics, but also on flow characteristics. The response depends on both the thermal capacity of the sensor and the heat transfer coefficient between the sensor and its environment. Since the sensor response varies with changes in flow (changing the heat transfer coefficient), the frequency compensation of the amplifier must be readjusted whenever the mean flow changes.

The constant temperature type of compensating circuitry overcomes the primary disadvantage just mentioned in the constant current system by using a feedback loop. As the velocity past the sensor increases, the sensor will tend to cool with a resulting decrease in the resistance. This resistance decrease will cause the voltage to decrease, thus changing the input to the amplifier. The phase of the amplifier is such that this decrease in voltage will cause an increase in the output of the amplifier in order to increase the current through the sensor. The output of the constant temperature system is the voltage output of the amplifier, which in turn is the voltage required to drive the necessary current through the sensor.

TABLE 32. FORCE-MOMENTUM METER EVALUATION

Evaluation Parameter		Scale		
1	Range	☒ Poor	☐ Fair	☐ Good
2	Accuracy	☐ Poor	☐ Fair	☒ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☒ Moderate	☐ Slight
7	Flow Obstruction	☐ High	☒ Moderate	☐ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☒ Poor	☐ Fair	☐ Good
10	Power Requirements	☒ High	☐ Medium	☐ Low
11	Site Requirements	☒ High	☐ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☒ High	☐ Moderate	☐ Slight
13	Simplicity and Reliability	☒ Poor	☐ Fair	☐ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☒ High	☐ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☐ Moderate	☒ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☒ Poor	☐ Fair	☐ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☒ High	☐ Medium	☐ Low
25	Portability	☒ No		☐ Yes

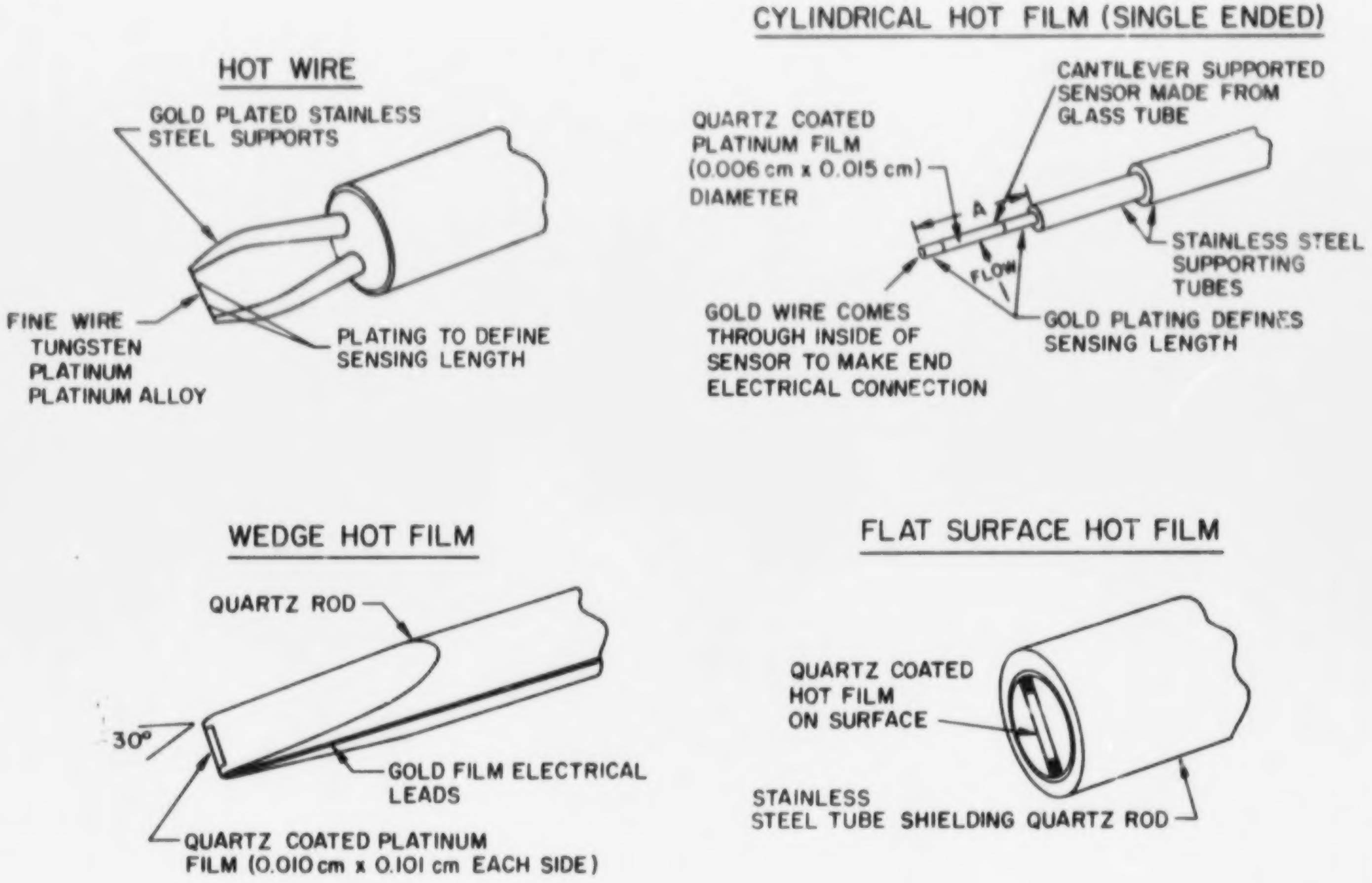

HOT WIRE
GOLD PLATED STAINLESS STEEL SUPPORTS
FINE WIRE TUNGSTEN PLATINUM PLATINUM ALLOY
PLATING TO DEFINE SENSING LENGTH
CYLINDRICAL HOT FILM (SINGLE ENDED)
CANTILEVER SUPPORTED SENSOR MADE FROM GLASS TUBE
QUARTZ COATED PLATINUM FILM (0.006 cm x 0.015 cm) DIAMETER
A
FLOW
STAINLESS STEEL SUPPORTING TUBES
GOLD WIRE COMES THROUGH INSIDE OF SENSOR TO MAKE END ELECTRICAL CONNECTION
GOLD PLATING DEFINES SENSING LENGTH
WEDGE HOT FILM
QUARTZ ROD
30°
GOLD FILM ELECTRICAL LEADS
QUARTZ COATED PLATINUM FILM (0.010 cm x 0.101 cm EACH SIDE)
FLAT SURFACE HOT FILM
QUARTZ COATED HOT FILM ON SURFACE
STAINLESS STEEL TUBE SHIELDING QUARTZ ROD

Figure 32. Typical Hot-Tip Element Configurations

Ling (58) introduced the hot-film probe for use in liquid flows in 1955. Since then, a number of investigations have been carried out in liquids with only a few being successful. In most of these, the film was placed away from the wall since its size can interfere with the detailed measurements required in the sub-layer region. Indeed, different configurations of film probes have produced very different results within the same experiment even for the simple case of measuring velocity profiles in turbulent flows. The one type of film probe that holds promise of being applied to sewer flow is the flush-mounted probe, because the backing material does not interfere with the flow field and has the best chances of physical survival in the sewer environment. Very little research has been done to determine the feasibility of using flush-mounted, hot-film sensors for quantitative measurements in water because the electrolysis problem has only recently been solved through the use of quartz coatings. Runstadler, et al (59) give a very concise summary of the factors that significantly affect the table non-drift operation of hot-film probes in water. Hot-tip probes are evaluated in Table 33.

Cold-tip Meters

Harris (60) has described a sort of inverse of the hot-tip meters. The operating principle of his device involves the use of a thermoelectric cooling unit to provide a cold surface in contact with the stream flow. The temperature of the cold surface is then, of course, a function of stream velocity and the other factors noted in the discussion of hot-tip devices. This approach would offer advantages when applied to a fluid containing dissolved gases which tend to come out of solution when heated by a hot-tip type element. The temperature difference between the probe and the fluid must be even smaller than with the hot-tip devices, however, because most storm and combined sewer flows are closer to their freezing temperatures than their boiling points. The ice formations will affect calibration. Although interesting, it is not felt that cold-tip devices are ready, as yet, for application as sewage flow measuring devices. Most of the evaluation comments of Table 33 hold for cold-tip devices also.

Boundary Layer Meter

Laub (61, 62) and Barlow (63) describe a boundary layer meter wherein the heater and temperature measuring elements are on the outside of the conduit. With this design, only the layer of fluid immediately adjacent to the inner wall of the conduit is heated. Response times of under a second are possible as is temperature compensation. There is no obstruction to the flow in such a design, so the meter introduces no additional head loss. Errors can result from changes in fluid composition which would change the parameters affecting thermal devices (e.g., viscosity, specific heat, thermal conductivity, etc.). The device would appear to overcome many of the other objectionable features of the hot-tip designs, however. Good ranges (50:1) and accuracies (±1%) are achievable under ideal circumstances, but should not be expected in a sewage measurement application.

TABLE 33. HOT-TIP METER EVALUATION

Evaluation Parameter		Scale		
1	Range	☐ Poor	☒ Fair	☐ Good
2	Accuracy	☒ Poor	☐ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☐ No		☒ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☒ High	☐ Moderate	☐ Slight
7	Flow Obstruction	☐ High	☒ Moderate	☐ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☒ Fair	☐ Good
10	Power Requirements	☐ High	☒ Medium	☐ Low
11	Site Requirements	☐ High	☒ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☒ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☒ Fair	☐ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☒ High	☐ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☒ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☒ Fair	☐ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☒ Fair	☐ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☒ High	☐ Medium	☐ Low
25	Portability	☒ No		☐ Yes

As in the case of thermal probes, it is possible to locate a number of sensors along the vertical (here, around the periphery of the conduit if round) and thereby measure depth as well as velocity under open channel flow conditions. Such designs have recently become available, but experience with them is limited as yet.

Eshleman and Blase (64) describe a related device which is more properly termed a thermal time-of-flight flowmeter. It is actually a tracer technique, but here the tracer is energy in the form of heat. A heater element is used to introduce a slug of heat (a thermal wave) into the boundary layer flow. Temperature compensated thermistors, located a known distance downstream, were used to detect the heat pulse (extremely complex electronics were required) and its time of flight was determined. This velocity could be related, through calibration, to mean flow velocity, but accuracy and repeatibility were poor in the device as designed. Thermal boundary layer meters are evaluated in Table 34.

ELECTROMAGNETIC

In 1839, Michael Faraday attempted to measure flow by lowering large electrodes into the Thames River near the Waterloo bridge. This experiment did not succeed. Faraday's Law states that if a conductor (in this case the flowing fluid) is passed through a magnetic field, a voltage will be inducted across the conductor at right angles to both the lines of flux and the direction of motion and will be proportional to the velocity of the conductor and the strength of the magnetic field.

Today, there are a number of successful designs of electromagnetic flowmeters, all based upon Faraday's Law. All share the same fundamental components, but they differ in their design of implementation, ranging from meters for measuring pressurized flow in pipes to point velocity sensors. Their earliest successful adaptations were in sea-water applications such as oceanographic current meters and logs for indicating ships' speed. When applied to a pipe flowmeter, the fundamental components are a piece of straight pipe, electrical coils to produce a magnetic field perpendicular to the axis of the pipe, and a pair of diametrically-opposed electrodes orthogonal to the magnetic field and the pipe axis (Figure 33). For a velocity probe (Figure 34) the same fundamental components are involved, but they are in a sort of "inside out" arrangement as compared to the pipe meter. The theory of electromagnetic flow measurement is treated in the monograph by Shercliff (65).

There are a number of parameters of the flowing stream that must be considered in the application of electromagnetic flowmeters. These include: corrosion levels, abrasion levels, possible magnetic content, presence of entrained gases, and the ability to coat electrodes. The devices can tolerate low fluid conductivity, e.g., some work with distilled water, and design features can be incorporated to overcome most problems posed by undesirable fluid characteristics.

TABLE 34. THERMAL BOUNDARY LAYER METER EVALUATION

	Evaluation Parameter	Scale		
1	Range	☐ Poor	☐ Fair	☒ Good
2	Accuracy	☐ Poor	☐ Fair	☒ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☐ No		☒ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☐ Moderate	☒ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☒ Poor	☐ Fair	☐ Good
10	Power Requirements	☐ High	☒ Medium	☐ Low
11	Site Requirements	☐ High	☒ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☒ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☒ Fair	☐ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☒ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☐ Moderate	☒ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☒ High	☐ Medium	☐ Low
25	Portability	☒ No		☐ Yes

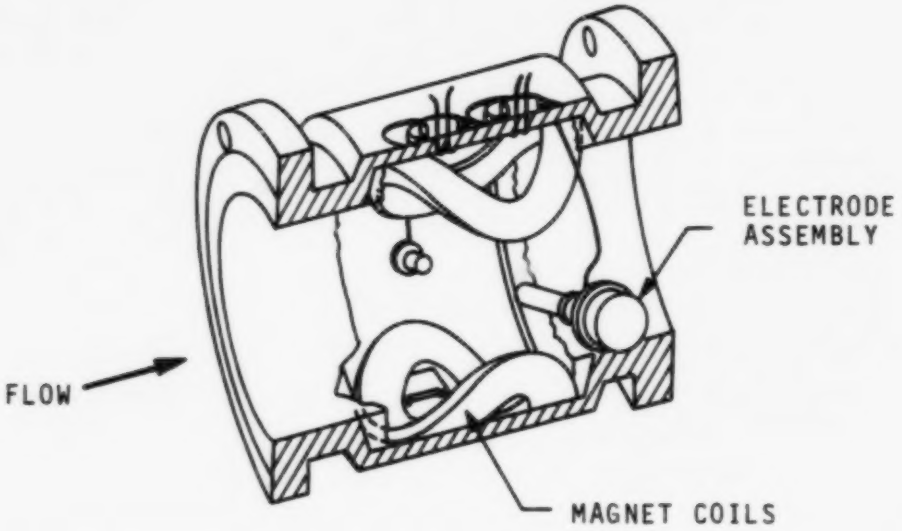

ELECTRODE ASSEMBLY
FLOW
MAGNET COILS

Figure 33. Components of an Electromagnetic Pipe Flowmeter

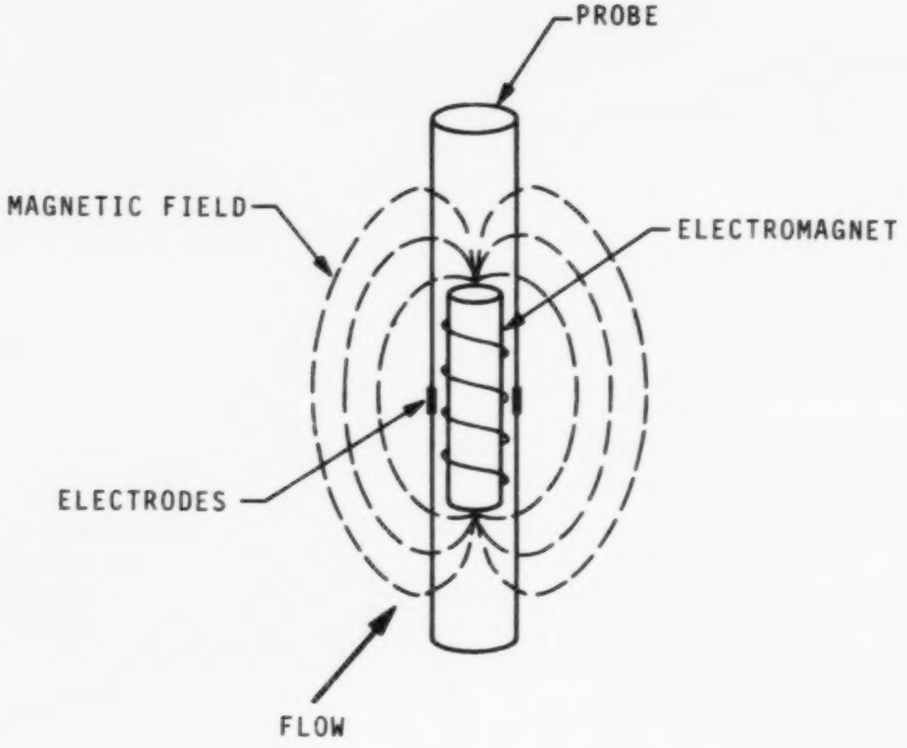

PROBE
MAGNETIC FIELD
ELECTROMAGNET
ELECTRODES
FLOW

Figure 34. Components of an Electromagnetic Velocity Probe

An alternating polarity magnetic field (ordinarily or at near 60 Hz) is usually generated to avoid thermoelectric effects, electro-chemical effects, and DC detection problems. A difficulty is that the alternating magnetic field can cause a quadrature voltage (induced noise) problem resulting in an offset in the zero point (thus indicating flow when there is none). Quadrature is not constant, but can change due to electrode fouling (5-10 percent output zero shifts are not uncommon when electrode coating occurs). The problem is reduced by using self-cleaning electrodes and superimposing a signal equal in amplitude but 180 degrees out of phase (null adjustment). One design uses a quadrature rejection circuit to virtually eliminate zero shifts. Although normally used only under full pipe flow conditions, an electromagnetic pipe flowmeter will work if the pipe is less than full (e.g., down to about half), but an additional measurement, the fluid depth, is required to determine flow rate. It is also possible to mount a number of sensors up the wall of the conduit to measure both velocity and depth. Such an arrangement should be capable of measuring both open channel and pressurized flows. Except in attended use as a current meter, the probe configuration, because of its necessary obstruction to the flow, is not as desirable for measuring storm or combined sewer flows.

These devices have only relatively minor disadvantages (fouling of electrodes in some designs, susceptibility to the presence of stray electrical and magnetic fields) except for their relatively high power consumption, which makes battery operation for extended periods impractical. Electromagnetic flowmeters have a number of inherent advantages. They are capable of very high accuracies (better than ±1% of full scale) over fairly wide ranges (20:1 or more in many standard designs, and higher in configurations mentioned above) and can measure flow in either direction. They introduce very little pressure loss, have no moving parts, their response time is rapid (less than one second), and output is linear. The devices are fairly expensive, however. Electromagnetic flowmeters are evaluated in Table 35.

ACOUSTIC

The scientific use of acoustic principles in instrumentation today has its roots in the SOund Navigation And Ranging (SONAR) equipment developed during the Second World War. The fundamental principles were known, of course, before that time, and the depth of wells has long been measured by discharging a blank shell from a gun and using a stopwatch to determine the echo return time. Because most equipment in use today operates at frequencies above the audio range, the term ultrasonic is used by many writers when referring to this class of devices. A very recent article by Liptak and Kaminski (66) provides a comprehensive survey of the field.

Acoustic meters have two classes of application in flow measurement today; as secondary devices to continuously monitor liquid level (or stage) and as primary devices to measure actual flow velocity. Common

TABLE 35. ELECTROMAGNETIC FLOWMETER EVALUATION

Evaluation Parameter		Scale		
1	Range	☐ Poor	☒ Fair	☐ Good
2	Accuracy	☐ Poor	☐ Fair	☒ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☐ No		☒ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☐ Moderate	☒ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☒ Poor	☐ Fair	☐ Good
10	Power Requirements	☒ High	☐ Medium	☐ Low
11	Site Requirements	☐ High	☒ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☒ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☒ Fair	☐ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☒ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☐ Moderate	☒ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☒ Fair	☐ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☒ High	☐ Medium	☐ Low
25	Portability	☒ No		☐ Yes

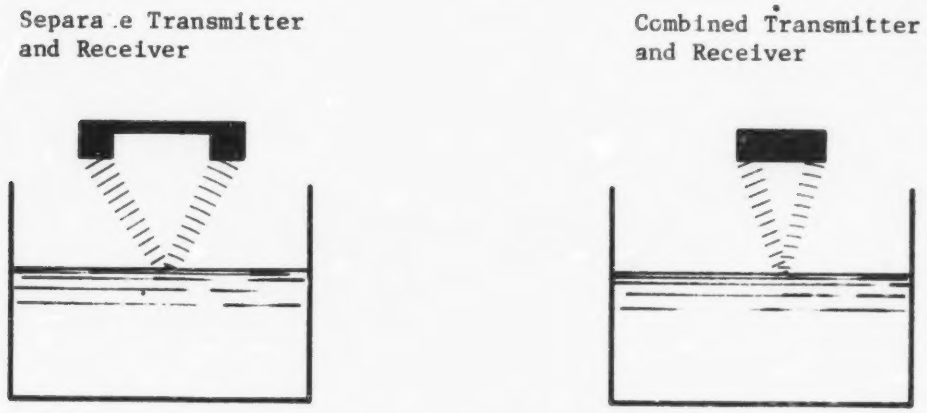
to both is the measurement of the travel time of acoustic pulses between a transmitter and receiver. The two applications will be discussed in turn.

Continuous measurement of liquid depths is accomplished by measuring the time required for an acoustic pulse to travel to the liquid-air interface (where it is reflected) and return. The transmitter and receiver may be separate physical entities or may be combined. There are two fundamental physical arrangements as depicted in Figure 35. One uses air path measurement and the other uses liquid path measurement. Although better short-term accuracy can be achieved with liquid path arrangements, for wastewater applications the air path arrangement is more common since it simplifies installation, is independent of fluid velocity, and avoids any contact with the flow.

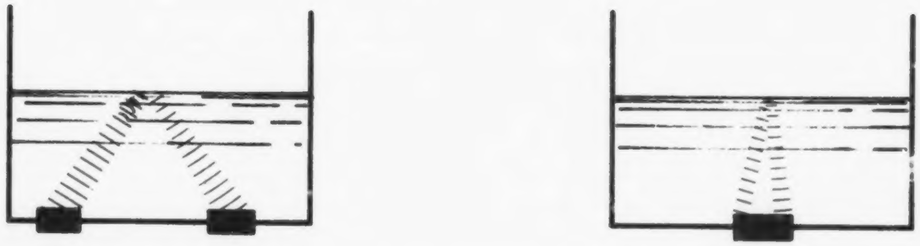
When flow (velocity) measurement is to be accomplished, it is not the velocity of sound that is measured but, rather, the differential velocity between travel in the upstream and downstream directions. Since the acoustic devices are actually velocity sensors, the area and vertical velocity profile across the flow must be known. For open-channel flow, the depth must also be determined and, understandably, manufacturers generally use acoustic level sensors for this purpose. For widely varying flow depths, sensor placement is critical, and more than one pair of sensors may be required.

As noted by Liptak and Kaminski (66), acoustic flow sensing or measuring equipment (like sonar) falls into one of two rather broad categories, passive and active. In passive operation, the transducer does not emit any acoustic energy but simply acts as a receiver. Flow switches (on/off state indicators) usually sense the noise generated by the flowing stream and provide indication that some predetermined threshold value has been exceeded. Passive flowmeters are either immersed in the flowing stream or, as in the case of open-channel flow, can be located in air. Fundamentally, they operate on the idea that, as the flow in the conduit increases, the sound level also increases in some direct and repeatable manner. Only two commercial firms offer such equipment, and considerable work would be required before they could be reliably used in a storm or combined sewer flow measurement application. This is discussed further in Section VIII.

There are a number of active acoustic flowmeter designs available today. They all use at least one pair of transducer sets (transmitter/receiver), so located that one operates against the direction of flow and the other operates with the flow. A few physical arrangements are indicated in Figure 36. Differences occur in the details of implementation; e.g., sensor geometry, sensors immersed in the flow or fastened to the outside of the conduit, sensors projecting into the flow, flush mounted, or recessed in wells, etc. There are also three fundamental approaches to determining the velocity of the flow in present equipment designs - differential time circuits, total travel time circuits, and "sing-around" circuits.


Separate Transmitter and Receiver
Combined Transmitter and Receiver

a. Air Path Measurement



b. Liquid Path Measurement

Figure 35. Physical Arrangements of Acoustic Depth Sensors

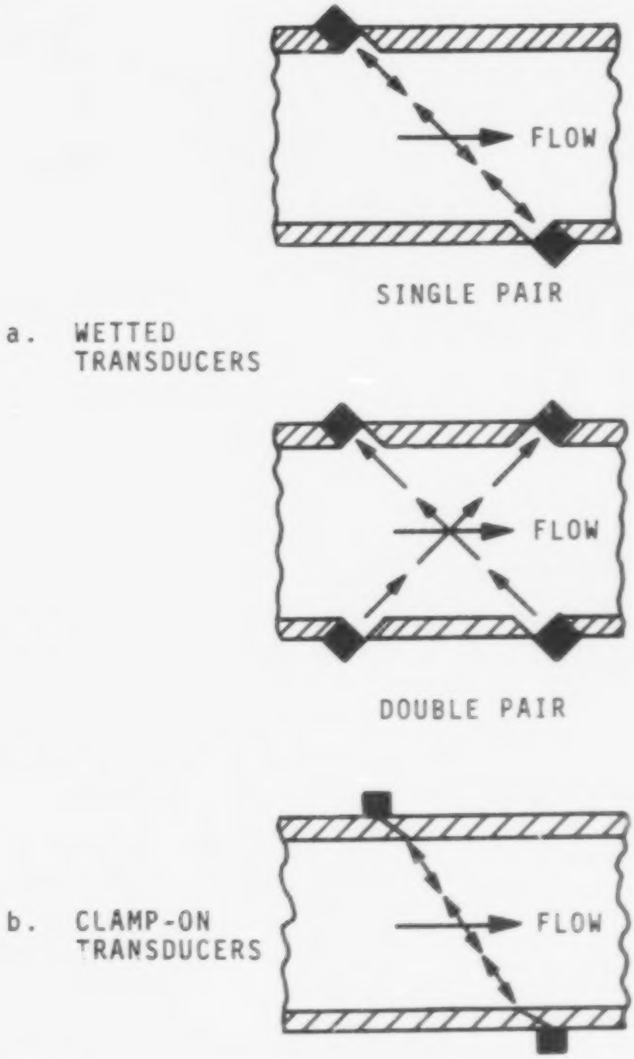

FLOW
SINGLE PAIR
a. WETTED TRANSDUCERS
FLOW
DOUBLE PAIR
b. CLAMP-ON TRANSDUCERS
FLOW

Figure 36. Physical Arrangements of Acoustic Velocity Sensors

In the differential time circuit, the difference in the time of arrival of acoustic pulses, which are triggered simultaneously at each end of a diagonal path across the stream, is measured directly. When the two transmitters send signals simultaneously toward each other, the flow of water will increase the effective speed of one and decrease that of the other. The signal transmitted in the downstream direction arrives first, and is used to start a timer, which runs until the signal transmitted in upstream direction arrives. This time increment is thus the differential between the total travel times involved and is linearly proportional to the fluid velocity. The average total travel time must also be recorded to compensate for changes in the speed of sound of the fluid. This technique is not well suited for small conduits with low velocities because the time differences may be on the order of nanoseconds.

In the total travel time circuit, the flow velocity is computed by resolving the velocity component in the flow direction as computed from the sequential travel times required for pulses to travel; e.g., first from the downstream sensor to the upstream sensor and then from the upstream sensor to the downstream sensor. Since the total travel times are used, changes in the speed of sound in the fluid are automatically compensated for. Errors in indicated velocity are a linear function of timing errors in either direction.

The sing-around circuit technique is sometimes referred to as a pulse-repetition frequency technique. In it, cumulative measurements of travel times are made by using the received pulse at the far end of an acoustic path to immediately trigger a second pulse from the originating transmitter. Arrival of the second pulse triggers a third, and so on. Either the total time required for completion of a fixed number of cycles is measured or the cycling rate is reduced to a continuous, pulse-repetition frequency. Where a single pair of transducers is employed, measurements are made in one direction for a given period and then in the other. Sometimes two pairs of transducers are used (tuned to different frequencies) and operated simultaneously. By using the difference in the upstream and downstream frequencies to determine the flow velocity, the dependence upon the sound velocity of the fluid is eliminated.

From the foregoing discussion it can be seen that one of the most important factors in any acoustic flow measuring device is the accurate measurement of time (or its inverse, frequency). As noted by Smoot (42), four different signal-recognition methods have been used in various designs on the market today - the leading-edge detection method; a method that utilizes the differential of the voltage time pulse train; the zero-crossover method; and the phase difference method. There are advantages and disadvantages to each, and competing claims have been made by proponents of one method or another.

In summary, acoustic liquid velocity sensors have not yet reached the state of the art where they can be considered as simple, off-the-shelf items for wastewater flow application. They offer many advantages, but tend to be relatively expensive for some installations and require highly trained technicians for their repair and maintenance. Accuracies to ±0.5% of full scale are achievable, but numbers as high as ±5% must often be considered more typical, especially for a wastewater application. Ranges from 20:1 to 1000:1 are possible, depending upon design details discussed earlier. Acoustic meters are evaluated in Table 36.

DILUTION

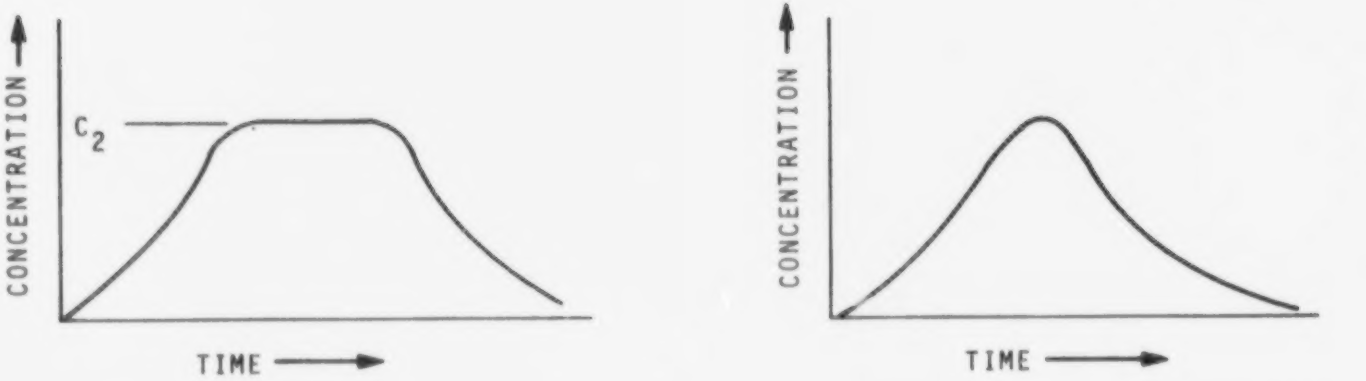
The dilution method can be used to measure discharge directly without experiencing many of the difficulties of other devices. It can be used in any shape of conduit flowing either partially full or under pressure and does not involve the stream dimensions or measurement of fluid properties such as pressure, temperature, or even level. It produces no pressure loss, requires no drop in hydraulic grade line, offers no obstruction to the flow, and indicates flow rate directly by simple theoretical formulas.

Basically, the measurement of discharge by dilution methods depends upon determining the degree of dilution of an added tracer solution by the flowing water. Spencer and Tudhope (67) have noted that dilution methods have been known since at least 1863. Although the earliest tracers were brine, radioactive and fluorescent dye tracers are more commonly used today. They have greatly reduced the quantities of tracer substance required and increased the accuracies achievable in many instances. For example, the fluorescent dye Rhodamine WT can be quantitatively detected with an accuracy of ±1% in concentrations of less than 10 parts per billion.

There are two general techniques used in dilution flow measurement: the constant-rate injection method and the total-recovery method (called the slug-injection method by some writers). These are depicted in Figure 37. As its name implies, the constant-rate injection method requires that the tracer solution be injected into the flow stream to be measured at a constant flow rate for a given period of time. The discharge is determined by the simple formula given in Figure 37a involving the background concentration in the stream (if any), the tracer concentration and injection rate (both presumably controlled and known), and the measured plateau of the concentration-time curve at the measurement site. In the total-recovery method, a known quantity of the tracer solution is introduced into the stream in any one of a number of ways, and a continuous sample is removed at a uniform rate for the entire time needed for the tracer wave to pass, in effect integrating the concentration-time curve. This integral is sometimes approximated by using a series of successive discrete samples. The discharge is simply related to the total quantity of tracer injected and the integral of the concentration-time curve as indicated in Figure 37b. This latter method requires that the total volume of the tracer be accounted for at the measurement site.

TABLE 36. ACOUSTIC METER EVALUATION

Evaluation Parameter		Scale		
1	Range	☐ Poor	☐ Fair	☒ Good
2	Accuracy	☐ Poor	☐ Fair	☒ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☐ No		☒ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☒ Moderate	☐ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☒ Fair	☐ Good
10	Power Requirements	☐ High	☒ Medium	☐ Low
11	Site Requirements	☐ High	☒ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☒ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☒ Fair	☐ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☒ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☐ Moderate	☒ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☒ Fair	☐ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☒ High	☐ Medium	☐ Low
25	Portability	☒ No		☐ Yes



a. CONCENTRATION-TIME CURVE FOR CONSTANT-RATE INJECTION METHOD.

$$Q = \left(\frac{C_1 - C_2}{C_2 - C_o}\right) q$$

Q IS FLOW RATE OF STREAM

q IS FLOW RATE OF CHEMICAL

C_o IS BACKGROUND CONCENTRATION OF STREAM

C_1 IS CONCENTRATION OF CHEMICAL INJECTED

C_2 IS CONCENTRATION OF STREAM PLATEAU

b. CONCENTRATION-TIME CURVE FOR SLUG-INJECTION METHOD.

$$Q = \frac{v\ C_1}{\int_o^\infty (C - C_o)\,dt}$$

Q IS FLOW RATE OF STREAM

v IS VOLUME OF CHEMICAL INJECTED

C_o IS BACKGROUND CONCENTRATION OF STREAM

C_1 IS CONCENTRATION OF CHEMICAL INJECTED

C IS INSTANTANEOUS STREAM CONCENTRATION

Figure 37. Chemical Dilution Methods

Although each of these dilution methods has its advantages and limitations, they are basically similar. A fluorometer, geiger counter, or some other appropriate instrument is required for determining sample concentration, a method of extracting a sample for analysis is needed, and a device to either inject tracer at a steady known rate or withdraw sample at a steady (but not necessarily known) rate is required. Both methods require complete vertical and lateral mixing at the measurement site. Since vertical mixing usually occurs rather rapidly as compared to lateral mixing, the latter usually controls the distance required for complete mixing, and hence, the distance between the injection and measurement sites. Cobb and Bailey (68) provided a thorough discussion of dye-dilution methods, in which they recommend calibration of the measurement reach (the length between injection point and measurement point) to ascertain the required mixing length and to determine relative tracer losses (due to adsorption by pipe walls or solids for example).

The effect of inflow or outflow in the measurement reach will cause the point of flow determination to shift for a dilution-type measurement. Where there is no inflow or outflow in the measurement reach, the measured flow will be the flow occurring at any point in the reach. If there is inflow within the measurement reach and it is totally mixed with the stream at the measurement point, the flow measured will be that at the measurement point, not the injection point. If there is outflow from the measurement reach but after complete mixing of the tracer has occurred, the flow measured will be that at the injection point, not the measurement point.

Replogle, et al (69) report achieving accuracies of better than ±1% in laboratory flume measurements using dye dilution techniques and Kilpatrick (70), making dye-dilution discharge measurements on the Laramie River under total ice cover, obtained agreement of better than +2% (+0.6% in one case) as compared with current meter measurements. Shuster (71) reports obtaining accuracies better than ±3% using radioisotopes as a tracer. He found that, in the concrete-lined trapezoidal channel used in his study, the length required for almost complete mixing was 250 to 300 times the flow depth. Ranges of 1000:1 or better can be achieved. One popular use of the technique is to calibrate other primary devices. The main disadvantages of dilution techniques are the cost associated with the instrumentation required for determining tracer concentrations, the lack of ruggedness in some of their designs, and the required training for operator personnel. The dilution method is evaluated in Table 37.

OTHER

There are a number of less widely used flow measurements that do not fit well under any of the more traditional classifications discussed so far. They will be discussed here.

TABLE 37. DILUTION METHOD EVALUATION

Evaluation Parameter		Scale		
1	Range	☐ Poor	☐ Fair	☒ Good
2	Accuracy	☐ Poor	☐ Fair	☒ Good
3	Flow Effects on Accuracy	☐ High	☒ Moderate	☐ Slight
4	Gravity & Pressurized Flow Operation	☐ No		☒ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☐ Moderate	☒ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☐ Fair	☒ Good
10	Power Requirements	☐ High	☒ Medium	☐ Low
11	Site Requirements	☐ High	☐ Moderate	☒ Slight
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☒ Slight
13	Simplicity and Reliability	☐ Poor	☒ Fair	☐ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☒ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☐ Moderate	☒ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☒ Fair	☐ Good
19	Self Contained	☒ No		☐ Yes
20	Precalibration	☒ No		☐ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☒ High	☐ Medium	☐ Low
25	Portability	☐ No		☒ Yes

Doppler

A fairly recent technique for measuring the velocity of flow in a liquid stream makes use of the doppler effect. Such devices, called scatter frequency shift devices by some writers, may utilize any one of a number of forms of radiated energy, including ultrasonic wavelengths, infrared, ultraviolet, laser, etc. They operate on the principle that when a beam of energy is projected into a nonhomogeneous liquid, it is scattered by suspended particulate matter in the fluid, and some of it is reflected back to a receiver. Owing to the doppler effect, the frequency of the return signal reflected from the scatterers in the fluid differs from that of the transmitted signal provided there is a net movement of the nonhomogeneities with respect to the transmitter or receiver. This frequency shift is directly related to the velocity of the scatterers (among other factors) and, if they are stationary with respect to the liquid, to the flow velocity itself. The scatterers can range from solid particles to gas bubbles, the only requirement being that they move at the same velocity as the flow transporting them.

It is pointed out that such devices usually sense velocity only in a very small region (where the transmitter and receiver signals cross) and, hence, knowledge about the velocity profile is normally necessary in order to infer total flow quantities. For example, at acoustic frequencies of 5-10 MHz, the reverberation volume is on the order of 0.003m (0.01 ft) in diameter. This has been used to advantage in laboratory studies of boundary layer development using laser-doppler devices.

Acoustic-doppler devices have been investigated by the U.S. Geological Survey over a period of several years. As noted by Smoot (42), their experience has been less than totally successful. Under good conditions, i.e., size and concentration of suspended particulate matter, the meter functions very well, but when concentrations are too low (or particle sizes too small) or too high, there is either sporadic or no signal return. A further limitation of such devices is the need for temperature and composition compensation. Under ideal conditions, Doppler meters can yield accuracies of ±0.5% over ranges of 10:1 or higher. They are expensive, however, and little applications data are available. Doppler meters are evaluated in Table 38.

Optical

The U.S. Geological Survey and the California Department of Water Resources have developed a meter which uses optical methods to determine surface velocities of streams; see Buchanan and Somers (49) or Smoot (42). The meter is a stroboscopic device and essentially

TABLE 38. DOPPLER METER EVALUATION

Evaluation Parameter		Scale		
1	Range	☒ Poor	☐ Fair	☐ Good
2	Accuracy	☐ Poor	☐ Fair	☒ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☐ No		☒ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☒ High	☐ Moderate	☐ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☒ Fair	☐ Good
10	Power Requirements	☐ High	☒ Medium	☐ Low
11	Site Requirements	☐ High	☒ Moderate	☐ Slight
12	Installation Restrictions or Limitations	☐ High	☒ Moderate	☐ Slight
13	Simplicity and Reliability	☐ Poor	☒ Fair	☐ Good
14	Unattended Operation	☐ No		☒ Yes
15	Maintenance Requirements	☐ High	☒ Medium	☐ Low
16	Adverse Ambient Effects	☐ High	☐ Moderate	☒ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☒ Fair	☐ Good
19	Self Contained	☐ No		☒ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☒ High	☐ Medium	☐ Low
25	Portability	☒ No		☐ Yes

consists of a low-power telescope, a set of mirrors on the periphery of a drum, a variable-speed motor that rotates the drum at precisely-controlled speeds, and a tachometer for determining drum rotational speed. Velocity measurements are made from an observation point above the stream. Light coming from the water surface is reflected by the mirrors into the lens system and eyepiece. By adjusting the rotational speed of the drum, the apparent motion of the water surface images reflected by the mirrors slows down and stops, appearing as if the surface of the water was being viewed while moving along exactly in pace with it. The velocity can be determined by knowing this "null" speed of rotation and the vertical distance from the water surface to the optical axis of the meter.

The meter is a light-weight, battery-powered unit that has no parts in contact with the flowing stream. It can be used for quite high velocity streams and for flows heavily laden with debris and sediment (it was developed for flood use). It is not useful for low-velocity, tranquil flows, but has been used successfully to measure velocities ranging from 1.5 to 15.2m/s (5 to 50 fps). The optical meter is evaluated in Table 39.

Electrostatic

A very recent development by Alger (72) is the electrostatic flow meter. The concept arose from the observation that a stream of water discharging from a pipe into air appeared to possess a surrounding electrical field or charge. Experimental tests have been run using water as the flowing medium. The voltage between two dissimilar metal pipe sections (electrically insulated from each other) was measured at different controlled rates of flow, most of which were within the laminar range.

It is well established that a potential difference exists between two different metals immersed in a fluid containing ions of the metals. This is observed in the experimental set-up just described when there is no flow. Increasing the flow rate was found to produce an immediate decrease in the voltage. Decreasing the flow rate, however, caused an increase in the voltage which required some time before it would steady out. The voltage levels were also functions of certain elements of the system geometry (e.g., length of insulation between the two pipe sections), the type of metal pipe sections (steel and copper were used), and perhaps of the nature of the fluid (e.g., conductivity) as well. The method at present requires that the pipe be flowing full and under pressure. It offers no obstruction to the flow, head loss, etc., and could be rather inexpensive if it utilizes the natural elements of a fluid-pipe system. It is presently the subject of continuing research and cannot be considered as fully understood or suitable for practical use at this time. Therefore, no further discussion will be given.

TABLE 39. OPTICAL METER EVALUATION

	Evaluation Parameter	Scale		
1	Range	☐ Poor	☒ Fair	☐ Good
2	Accuracy	☒ Poor	☐ Fair	☐ Good
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☒ Slight
4	Gravity & Pressurized Flow Operation	☒ No		☐ Yes
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☒ Low
6	Effect of Solids Movement	☐ High	☐ Moderate	☒ Slight
7	Flow Obstruction	☐ High	☐ Moderate	☒ Slight
8	Head Loss	☐ High	☐ Medium	☒ Low
9	Manhole Operation	☐ Poor	☒ Fair	☐ Good
10	Power Requirements	☐ High	☐ Medium	☒ Low
11	Site Requirements	☐ High	☐ Moderate	☒ Slight
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☒ Slight
13	Simplicity and Reliability	☐ Poor	☐ Fair	☒ Good
14	Unattended Operation	☒ No		☐ Yes
15	Maintenance Requirements	☐ High	☐ Medium	☒ Low
16	Adverse Ambient Effects	☒ High	☐ Moderate	☐ Slight
17	Submersion Proof	☐ No		☐ Yes
18	Ruggedness	☐ Poor	☐ Fair	☒ Good
19	Self Contained	☒ No		☐ Yes
20	Precalibration	☐ No		☒ Yes
21	Ease of Calibration	☐ Poor	☐ Fair	☒ Good
22	Maintenance of Calibration	☐ Poor	☐ Fair	☒ Good
23	Adaptability	☐ Poor	☐ Fair	☐ Good
24	Cost	☐ High	☐ Medium	☒ Low
25	Portability	☐ No		☒ Yes

Nuclear Resonance

Nuclear resonance flowmeters, as described by Replogle (8), exploit a property of molecular nuclei. In nuclear resonance, the nucleus is disturbed by precessional motions, which have a negligible effect upon molecular or chemical reactions. Essentially, nuclear resonance consists of observing the absorption of radio waves at a frequency determined by the ratio of the nuclear magnetic moment to its spin (called the gyromagnetic ratio) and the value of an applied magnetic field. In water molecules, it is particularly easy to observe nuclear resonance since hydrogen protons provide a very strong absorption signal. Resonance is observed by using a receiver to detect the rf energy lost from a transmitter. No resonance signal can then be detected until the transmitter power is reduced and sufficient time has elapsed so that the nuclei can relax to their normal distribution. This relaxation time is a characteristic of the nuclei and their environment and may be used to indicate the velocity of flowing fluids.

In the somewhat limited work that has been done, accuracies of ±0.5% of full scale have been achieved over a 10:1 range under full pipe flow conditions. This technique does not appear suitable for storm or combined sewer application at this time and, consequently, will not be discussed further.

Miscellaneous

It should not be supposed that the foregoing discussion has exhausted the possibilities of physical principles or design adaptations for measuring fluid flows. There are numerous other devices or methods such as: the Gibson (or water hammer) technique that requires the sudden closure of a valve or gate and pressurized pipe flow; Andersson screens, which require a reach of very regular channel and a track on which the screen car can travel; Danaides devices, in which flow rate is related to the depth of the liquid in a container which is discharging through calibrated orifices; fixed measuring palisades that consist of airfoil-shaped vanes extending across the flow and creating a differential pressure that is related to discharge; the closely related tilting palisades in which the flow is determined from the force required to prevent the palisade from tilting from the vertical; and so on.

These all have, in the writers' opinion, one or more limitations, when considered for a storm or combined sewer application, that are so severe as to make any adaptation of them unpractical. Therefore, they are not discussed at all.

SECONDARY DEVICES

A review of all of the secondary devices used in flow measurement is outside the scope of the present writing. There do exist, however, a number of devices that are called flowmeters by their manufacturers but which, in actuality, are secondary devices for measuring stage. They must be used with some form of primary device before true flow measurements can be made. A brief discussion of these devices will be given along generic lines.

As is the case with all secondary devices, there are three basic types of information that can be provided, either separately or in combination. These are an indication of flow rate (typical units are cfs, gph, mgd, etc.; such devices are sometimes referred to as indicators); a running total of flow to the observed moment (typical units are cu. ft., gal., m.g., etc.; such devices are sometimes called totalizers); and a record, ranging from a curve drawn in ink with a pen to a magnetic tape recording, of the rate of flow with time over some suitable period (hour, day, week, etc.; such devices are termed recorders). Additional features may include the ability to transmit the flow data to a remote site (transmitters, the corresponding instruments at the other end being termed receivers), the ability to operate in digital versus analog form, etc. The discussions will not deal with these topics, but will focus upon the method used to sense or measure water level or stage.

Float-in-Well. This is probably the oldest type of secondary device in existence. It is applied in a stilling well connected to the gage point of the primary device (weir, flume, etc.). The float-in-well essentially consists of a float of some suitable shape (sized for compatibility with the dimensions of the well) connected via a cable to a wheel and counterbalanced in some fashion so that the cable remains taut. As the float rises or falls with charges in water level, the cable rotates the wheel, which is connected either mechanically or electronically to the readout, recorder, or whatever. Discharge is determined by the use of cams, electronic circuits, etc., that are characterized for the primary device involved.

Float-in-Flow. In this type of secondary device, the float rides on the actual surface of the flow, directly sensing its level rather than indirectly sensing it as with a stilling well. Float shapes range from spherical, to scow or ski shaped, the latter being designed to minimize disturbances of the liquid surface, fouling by trash or debris, oscillations in the instrument, etc. The float is attached to a hinged arm that is directly or indirectly (e.g., by cable) connected to the main body of the instrument. Directly-connected designs should be immersion proof if they are to be used in storm or combined sewers with any history of surcharging. In indirectly-connected designs, where the main body of the instrument can be located above the high water level, it need not necessarily be immersion proof, but this feature never hurts.

Advantages of float-in-flow devices include: freedom from the requirement for a stilling well and purge system; direct (rather than indirect) sensing of the liquid level; and avoidance (in some designs) of cables, counterweights, etc., typical of float-in-well devices. Disadvantages include: possible fouling by trash or debris (which can result in erroneous readings or even physical damage); broad chart records in some instances due to the lack of damping of water surface oscillations that some stilling wells provide; and a more limited range due to the restrictions on arm length necessary at some installations.

Bubbler. In this type secondary device, a pressure transducer senses the back-pressure experienced by a gas which is bubbled at a constant flow rate through a tube anchored at an appropriate point with respect to the primary device. This back-pressure can be translated into water depth and subsequently related to discharge. Advantages include a lack of moving parts or mechanisms, a sort of self-cleaning action arising from the gas flow, and virtually no obstruction to the flow. One of its main disadvantages is that if the exit end base of the bubble tube becomes appreciably reduced due to build-up of contaminants from the flow, erroneous readings will result even though the instrument may appear to be functioning normally. Aspiration effects due to the velocity of the flow may also present problems.

Electrical. These secondary devices make use of some sort of change in electric circuit characteristics in order to indicate the liquid level. Most designs utilize a probe or some similar sensor which is immersed in the flow at the gage point. This sensor is a part of an electrical circuit, and its behavior in the circuit is a function of its degree of immersion. For example, the sensor could basically be an admittance-to-current transducer, providing a measure of depth based on the small current flowing from the sensor to the grounded stream. Changes in any electrical property (capacitance, resistance, etc.) can be used to sense liquid depth. Advantages are the absence of any moving parts, floats, cables, stilling wells, gas supplies, purge requirements and the fact that they cannot plug and are usually unaffected by build-up of sludge, algae, slime, mud, etc. The major disadvantage is the requirement for the sensing element to physically be in the flow. The presence of appreciable foam or floating oil and grease can cause errors in most designs.

In a somewhat different design belonging to this class, the probe is not actually in the stream but is periodically lowered, via a motor-pulley-cable arrangement, until it makes contact with the water surface, which completes a microampere circuit through the liquid to a ground return.

This signal reverses the motor, raising the probe above the surface of the liquid. As in the case with a float, the amount of cable paid out is the measure of stage. Although this design does not require immersion of the sensor in the flow, it does involve mechanical complexities and moving parts not characteristic of the other electrical secondary devices.

Acoustic. This type of secondary device is growing in popularity as prices decrease. Requiring no physical contact with the liquid, they enjoy all of the advantages listed for electronic designs. They were covered in the discussion of acoustic primary devices and will not be redescribed here. However, a few precautionary words will be given. For applications where space is restricted as in some manholes and small meter vaults, problems due to false echos may be encountered. This problem may be overcome at some sites by shielding the transducer, but accurate readings (at low flows at least) should not be expected for flows in round pipes or deep, narrow channels from most designs. Also, good results should not be expected if the surface of the flow is highly turbulent or foam covered as the reduced return signal may not be properly detected.

DISCUSSION

The evaluation tables of the various flow measuring devices and techniques are summarized in matrix form in Table 40. It is re-emphasized that these evaluations are made with a storm or combined sewer application in mind and will not necessarily be applicable for other types of flows.

Table 41 offers a different (and even more subjective) comparison of some of the primary devices or techniques that are currently being used to measure storm and combined sewer discharges. Each method is numerically evaluated in terms of its percent of achievement of several desirable characteristics. Dilution techniques as a class appear to be the most promising of all. In view of the current state of the art, however, their usefulness is probably greatest as a tool for in-place calibration of other primary devices. They have also been extremely useful for general survey purposes and have found some application as an adjunct to other primary devices during periods of extreme flow such as pressurized flow in a conduit that is normally open channel.

Acoustic open channel devices are also quite promising; but, because of their dependency upon the velocity profile and the frequently resulting requirement for several sets of transducers, they are presently only justifiable for very large flows in view of the expense involved. The usefulness of the Parshall flume is evidenced by its extreme popularity. The requirement for a drop in the flow is a disadvantage, and submerged operation may present problems at some sites. Known uncertainties in the head-discharge relations (possibly up to 5%) together with possible geometric deviations make calibration in place a vital necessity if high accuracy is required. Palmer-Bowlus type flumes are very popular

TABLE 40. FLOWMETER EVALUATION SUMMARY

	Range	Accuracy	Flow Effects on Accuracy	Gravity & Pressurized Flow Operations	Submergence or Backwater Effects	Effect of Solids Movement	Flow Obstruction	Head Loss	Manhole Operation	Power Requirements	Site Requirements	Installation Restrictions or Limitations	Simplicity and Reliability	Unattended Operation	Maintenance Requirements	Adverse Ambient Effects	Submersion Proof	Ruggedness	Self Contained	Precalibration	Ease of Calibration	Maintenance of Calibration	Adaptability	Cost	Portability
Gravimetric-all types	G	G	H	Y	L	H	H	M	P	M	H	M	P	Y	H	M	-	F	Y	Y	G	F	-	H	G
Volumetric-all types	P	G	H	Y	L	H	H	M	P	L	H	H	F	Y	H	M	-	F	Y	Y	G	F	-	H	N
Venturi Tube	P	G	S	N	L	S	S	L	P	L	H	H	G	Y	M	M	-	G	Y	Y	G	G	-	H	N
Dall Tube	P	G	S	N	L	M	S	L	P	L	H	M	G	Y	M	M	-	G	Y	Y	G	F	-	H	N
Flow Nozzle	P	G	S	N	L	S	S	M	P	L	H	M	G	Y	L	M	-	G	Y	Y	G	G	-	M	N
Orifice Plate	P	F	S	N	L	H	H	H	P	L	H	S	G	Y	H	M	-	P	Y	Y	G	P	-	L	Y
Elbow Meter	P	F	S	N	L	S	S	L	P	L	H	S	G	Y	L	M	-	G	Y	N	F	G	-	L	N
Slope Area	F	P	H	N	H	S	S	L	G	L	M	S	G	Y	L	M	-	G	Y	N	F	G	-	H	N
Sharp-Crested Weir	F	F	M	N	M	H	H	H	F	L	M	M	G	Y	H	M	-	G	Y	Y	G	F	-	L	Y
Broad-Crested Weir	F	F	S	N	H	H	M	M	G	L	M	M	G	Y	L	M	-	G	Y	N	F	F	-	L	N
Subcritical Flume	F	F	S	N	L	S	S	L	F	L	M	S	G	Y	L	M	-	G	Y	Y	G	G	-	M	N
Parshall Flume	G	F	S	N	M	S	S	L	F	L	M	M	G	Y	L	M	-	G	Y	Y	G	G	-	M	Y
Palmer-Bowlus Flume	F	F	S	N	M	S	S	L	G	L	S	S	G	Y	L	M	-	G	Y	Y	G	G	-	L	Y
Diskin Device	F	F	S	N	M	M	H	L	G	L	S	S	G	N	H	H	-	F	Y	Y	Y	F	-	L	Y
Cutthroat Flume	G	F	S	N	L	S	S	L	F	L	S	S	G	Y	L	M	-	G	Y	Y	G	G	-	L	N
San Dimas Flume	G	F	S	N	L	S	S	L	F	L	S	S	G	Y	L	M	-	G	Y	Y	G	G	-	L	N
Trapezoidal Flume	G	F	S	N	L	S	S	L	F	L	S	S	G	Y	L	M	-	G	Y	Y	G	G	-	L	N
Type HS, H & HL Flume	G	F	S	N	H	M	S	H	G	L	M	M	G	Y	M	M	-	G	Y	Y	G	F	-	L	Y
Open Flow Nozzle	G	F	S	N	H	M	S	H	G	L	M	M	G	Y	M	M	-	G	Y	Y	G	F	-	L	Y
Float Velocity	G	P	H	N	L	S	S	L	G	L	S	S	G	N	L	H	-	G	Y	-	-	-	-	L	Y
Tracer Velocity	F	F	M	Y	L	S	S	L	G	M	S	S	F	Y	M	S	-	F	N	N	G	F	-	M	Y
Vortex Velocity	P	F	S	N	L	H	H	L	F	L	H	H	F	Y	H	S	-	P	Y	Y	P	F	-	H	N
Eddy-Shedding	F	F	S	Y	L	M	M	L	G	L	S	S	F	Y	M	S	-	F	Y	Y	G	F	-	M	Y
Turbine Meter	P	F	S	N	L	H	H	M	F	L	H	M	F	Y	H	S	-	F	Y	Y	G	F	-	H	N
Rotating-Element Meter	F	F	S	Y	L	H	M	L	F	L	S	S	G	N	H	H	-	G	N	Y	G	G	-	L	F
Vane Meter	P	F	S	N	L	M	H	L	F	L	S	M	G	Y	M	M	-	G	Y	Y	P	F	-	L	N
Hydrometric Pendulum	P	P	S	N	L	M	M	L	G	L	S	S	G	N	L	H	-	G	N	Y	P	P	-	L	Y
Target Meter	P	F	S	N	L	M	H	M	P	M	S	M	F	Y	H	S	-	F	Y	Y	G	F	-	H	N
Force-Momentum	P	G	S	N	L	M	M	L	[illegible]	M	H	H	F	Y	H	S	-	F	Y	Y	G	G	-	H	N
Hot-Tip Meter	F	P	S	Y	L	H	M	L	F	M	M	M	F	Y	H	M	-	F	Y	Y	G	F	-	H	N
Boundary Layer Meter	G	G	S	Y	L	S	S	L	P	M	M	M	F	Y	M	S	-	G	Y	Y	G	H	-	H	N
Electromagnetic Meter	F	G	S	Y	L	S	S	L	P	H	M	M	F	Y	H	S	-	F	Y	Y	G	G	-	H	N
Acoustic Meter	G	G	S	Y	L	M	S	L	F	M	M	M	F	Y	M	S	-	F	Y	Y	G	G	-	H	N
Doppler Meter	P	G	S	Y	L	H	S	L	F	M	M	M	F	Y	M	S	-	F	Y	Y	G	G	-	H	N
Optical Meter	F	P	S	N	L	S	S	L	F	L	S	S	G	N	L	H	-	G	N	Y	G	G	-	L	Y
Dilution	G	G	M	Y	L	S	S	L	G	M	S	S	F	Y	M	S	-	F	N	N	G	G	-	H	N

Legend:

F - Fair	N - No
G - Good	P - Poor
H - High	S - Slight
L - Low	Y - Yes
M - Medium or Moderate	

TABLE 41. COMPARISON OF MOST POPULAR PRIMARY DEVICES OR TECHNIQUES

Primary Device or Technique	Desirable Characteristic (% of Achievement)								Comments
	Range	Uncalib. Accuracy	Head Loss	Free From Upstream Effects	Free From Downstream Effects	Solids Bearing Liquids	Portability	Unattended Operation	
Dilution	100	100	100	100	100	100	100	80	Especially useful as a calibration tool
Acoustic (Open Channel)	100	100	100	60	90	95	80	100	Good in large flows but expensive.
Parshall Flume	90	95	80	90	80	90	70	100	Requires drop in floor.
Palmer Bowlus Flume	80	90	85	90	85	90	90	100	Good overall.
Current Meter	90	95	100	100	100	90	100	0	Results are very operator dependent.
Electromagnetic	50	100	100	100	100	100	0	100	Generally requires pressure flow
Acoustic (Pressure Flow)	100	100	100	60	90	95	0	100	Wetted transducers recommended.
Open Flow Nozzle	60	95	70	80	75	80	80	95	Good if head drop is available.
Sharp-Crested Weir	60	95	70	80	80	50	80	90	Will require frequent cleaning.
Flow Tube	50	100	95	40	100	95	0	100	Pressurized flow only.
Venturi Tube	20	100	90	70	100	90	0	100	Pressurized flow only.
Trajectory Coordinate	80	70	50	100	70	100	100	0	Requires free discharge.
Slope Area	80	50	100	20	100	100	100	0	Use as last resort.

3401-14

overall. They can be used as portable as well as fixed devices in many instances, are relatively inexpensive, and can handle solids in the flow without great difficulty.

All point velocity measuring devices have been lumped together in the current meter category. In the hands of a highly experienced operator, good results can be obtained (the converse is also true, unfortunately), and they are often used to calibrate primary devices in place or for general survey work. They are generally not suited for unattended operation in storm and combined sewer flows, however.

Electromagnetic flowmeters show considerable promise where pressurized flow is assured as do closed pipe acoustic devices. Neither can be considered portable if one requires that the acoustic sensors be wetted, a recommended practice for most wastewater applications.

Open flow nozzles and sharp-crested weirs are often used where the required head drop is available. Weirs will require frequent cleaning and are best used as temporary installations for calibration purposes. Flow tubes and venturis are only suitable for pressurized flow sites such as might be encountered, for example, at the entrance to a treatment plant.

Trajectory coordinate techniques, such as the California pipe or Purdue methods, require a pipe discharging freely into the atmosphere with sufficient drop to allow a reasonably accurate vertical measurement to be made, a situation not often encountered in storm or combined sewers. Slope area methods, as explained earlier, must generally be considered as producing estimates only and, consequently should be considered as the choice of last resort (despite their apparent popularity).

SECTION VII

REVIEW OF COMMERCIALLY AVAILABLE EQUIPMENT

The number of commercial firms that offer flow measuring or related equipment in the market place today is astoundingly large. Even when attention is limited to devices intended for liquid flowmetering, the number is still extremely large, probably well in excess of two hundred. Many manufacturers offer more than one type of primary device (and these typically in numerous models), and when combined with secondary device choices, the possible number is virtually overwhelming. Thus, complete coverage in a document of this sort is impossible.

The intent of this section is not, therefore, to provide a complete catalog which lists all manufacturers and discusses all their offerings. Rather an attempt has been made to select a large enough sampling of firms and products and describe each of these briefly but in enough detail to allow the reader to appreciate the actual implementation of the generic flow measurement methods discussed in Section VI. In accomplishing this, well over 120 manufacturers were contacted regarding product lines which might be recommended for application to the measurement of sewer flows. These firms ranged from very large, well known manufacturers that have offered a wide range of flow measuring equipment for over a century to relatively small organizations with a limited product line which has only recently been introduced. Devices were included which either illustrated one of the generic flow measurement methods or appeared to embody some novel or interesting implementation or variation. Even at that, there have undoubtedly been omissions, and some manufacturers of applicable equipment may have been overlooked. For this the writers wish to apologize and urge any firm that feels it has equipment suitable for sewer flow measurement (or has refined or improved its products) to communicate this information to them so that it might be included in any possible future update of this work.

The common format that has been followed in describing the commercially available equipment is straightforward and needs no explanation. However, a few comments on the information presented are needed. All information for a particular piece of equipment, including specifications, special claims for it, etc., has been taken from material supplied by its manufacturer in the form of descriptive brochures, specification sheets, technical writeups, user manuals, private correspondence, etc. It was not possible for the writers to verify or authenticate any of this information, so it must be accepted as manufacturer's claims only.

A comment on prices must also be made. Many manufacturers prefer to quote on an application basis. In view of this and the general economic conditions at the time of this writing (Fall 1974), prices where given should be considered approximations and should be verified with the particular manufacturer before using, even for general budgetary purposes. For example, one manufacturer who was contacted had just received a 25 percent increase from his forging contractor and could not tell what overall effect this would have on his prices; many suppliers are quoting prices on a delivery basis; etc. Because of this situation, attempts to obtain pricing information were curtailed; thus, some manufacturer's products have no prices given.

All illustrations in this section were taken from photographs, brochures, or other material provided by the respective manufacturers, and deep appreciation for permission to use them in this report is hereby acknowledged.

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MANUFACTURER: AMERICAN CHAIN AND CABLE COMPANY, INC.
ACCO BRISTOL DIVISION
WATERBURY, CONNECTICUT 06720
TELEPHONE (203) 756-4451

PRODUCT LINE: FLOWMETERING SYSTEM

DESCRIPTION:

The Bristol Series 840 L/V Monitoring System is designed to measure the level and velocity of sewer flow in larger (over 1m) sewer conduits. It is engineered primarily for manhole installation, can be positioned at existing manholes, and can be moved from one manhole to another for the purpose of making surveys of a sewage system. The monitoring system, shown in Figure A, consists of three major subassemblies: monitor assembly, probe controls, and a probe operator or hoist assembly. A single, self-cleaning probe is used for both velocity and flow level measurement. It is designed to withstand the corrosive environment of a sewer system and the impact of heavy objects.

The velocity of the flowing liquid is determined by a drag-type primary element which is located within the probe assembly. A hermetically-sealed flexure assembly is fastened to a cylindrical "target" area and contains a four-arm strain gage bridge together with the necessary compensating networks. As the moving stream impinges on the target area, an impact force is developed which is proportional to the square of the velocity of the stream. The impact force causes a linear deflection of the flexure, which is detected by the strain gage bridge. An excitation voltage from the strain gage power supply feeds the velocity sensor. Calibration is such that velocity of 0 to 3 m/s (0 to 10 fps) corresponds to an output signal of 0 to 20 mV. Thus, the force exerted on the target area is converted to an electrical output signal from the strain gage sensor. This millivolt signal is then amplified (in the Probe Controls cabinet) to 0 to 10V which, in turn, becomes the input signal to an electronic solid-state square root extractor. The square root extractor (also in the Probe Controls cabinet) converts the signal to a voltage signal linear with velocity.

The level sensing device in the probe ensures that the probe is always at a predetermined level of submersion in order to accurately measure the stream velocity at a reference level. It also detects the need for probe cleaning. An air bubbler arrangement is used for determining the level of probe submersion. This is done by sensing the bubbler backpressure. The bubbler outlet hole is located at the lower end of the probe adjacent to the target area of the velocity measuring device, in a position where it is not affected by the velocity of the flowing liquid. Should debris cause clogging, the probe has the capability of cleaning itself. This is accomplished by using the pneumatic cylinder

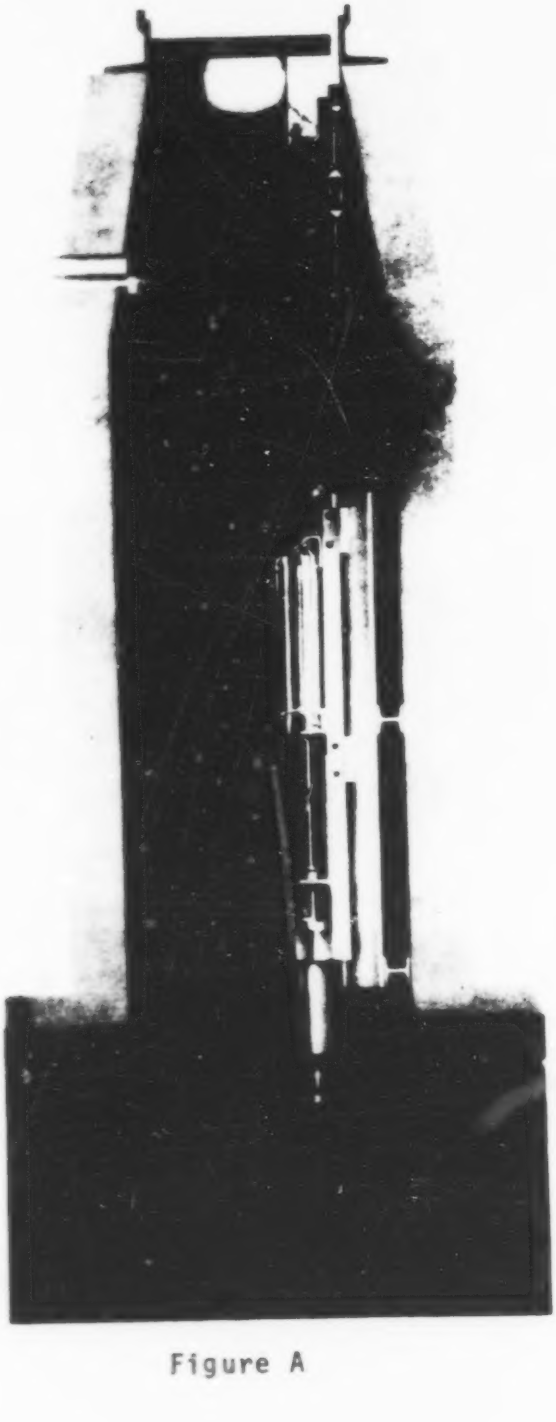


Figure A

to retract the probe through a tight-fitting wiper sleeve and then repositioning it. Simultaneously, a high-pressure air purge is directed at the velocity target area and also through the bubbler outlet hole. Normally the self-cleaning cycle is actuated at 15-minute intervals.

SPECIFICATIONS:

Size, Weight and Other Physical Facts:	Size and weight of the Monitor assembly can vary with the installation site requirements. A typical assembly for a 1.52m (5 ft) sewer conduit weighs approximately 136 kg (300 lbs.) and requires a trolley of 2.44m (8 ft) in length.
Power Requirements:	120V, 60 Hz, single phase, 30 ampere service.
Sewer Conduit Sizes:	1.22 to 6.1m (4 to 20 ft) (standard).
Liquid Level Ranges:	20.32 cm (8 in.) to full conduit
Velocity Measurement Range:	0 to 3 m/s (0 to 10 fps)
Air Supply:	Included in Probe Controls cabinet.
Sensitivity:	±0.64 cm (1/4 in.) change in liquid level.
Typical Accuracy:	Velocity, ±5% Level, ±0.64 cm (1/4 in.)
Repeatability:	No measurable changes in velocity and level over a period of one year.
Readout:	Analog-type panel meters included in Probe Controls cabinet.

OPTIONS

Installation Hardware:	As required.
Telemetry Output:	Two channels; one for velocity, one for liquid level. Either solid-state pulse duration or variable frequency may be considered. (Plug-in space is reserved

in the Probe Controls cabinet for either type of telemetry circuit boards, and for optional audio tone equipment.)

PRICE:

Prices are quoted at time of order based upon details of specifications-e.g. size, construction materials, etc.

COMMENTS:

Since this unit only provides the flow depth and velocity at about 15.2 cm (6 in.) below the free surface, calibration of the site would appear necessary in order to relate these two parameters to total discharge. The unit was not designed for smaller pipe sizes, i.e. under 1.22m (4 ft), and does not appear suitable for such applications.

MANUFACTURER: ASTRO DYNAMICS INC.
SECOND AVENUE
NORTHWEST INDUSTRIAL PARK
BURLINGTON, MASSACHUSETTS 01803
TELEPHONE (617) 272-3900

PRODUCT LINE: VOLUMETRIC FLOWMETERS

DESCRIPTION:

This company has developed a somewhat unique (patent pending) volumetric flowmeter. Its primary element essentially consists of a positive displacement (gear type) pump that is driven by a variable speed motor so as to maintain a zero pressure drop across the flowmeter. The secondary element is a counter that reads pump speed which is directly related to flow. A simplified block diagram of the unit is shown in Figure A.

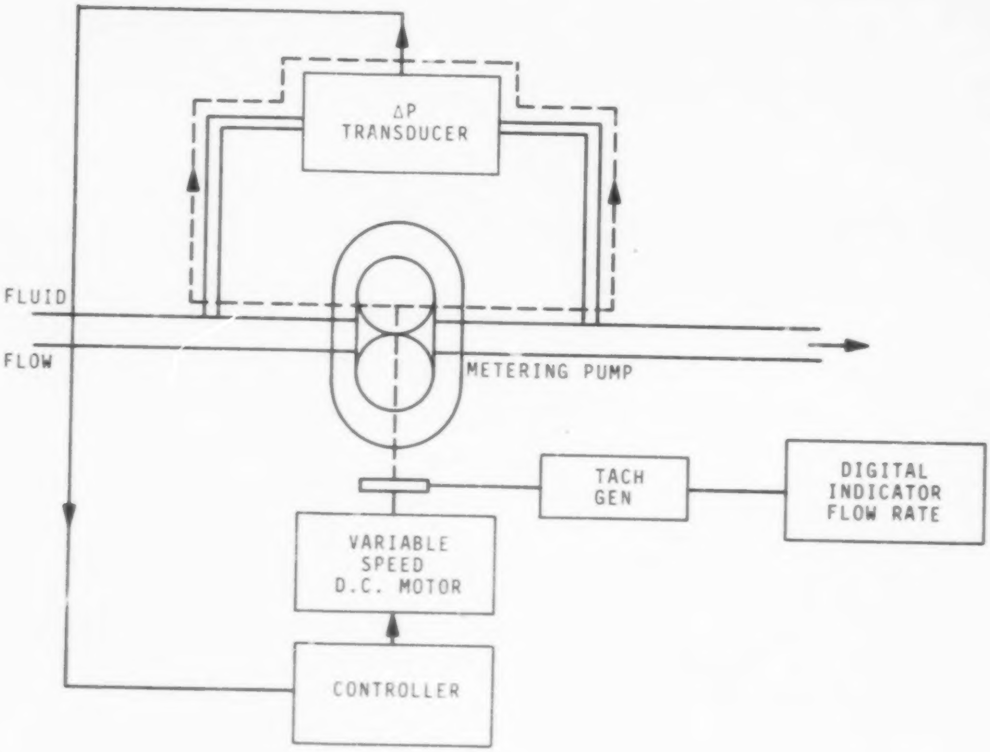

ΔP
TRANSDUCER
FLUID
FLOW
METERING PUMP
TACH
GEN
DIGITAL
INDICATOR
FLOW RATE
VARIABLE
SPEED
D.C. MOTOR
CONTROLLER

Figure A

The chief advantage of this approach would seem to arise from the fact that the slip factor, which is inherent in all such types of volumetric flowmeters, is greatly reduced with a nearly zero pressure differential. At the present time these flowmeters have only been built in rather small sizes, i.e., up to 577 ℓph (150 gph), but this is not an inherent limitation of the basic design. The unit was developed to meet a requirement for accuracies of ±0.2% of reading and repeatability of ±0.1% of reading; these have apparently been met. Ranges of up to 100:1 are possible, but 15:1 is more typical.

Units are available with either analog (0-10 VDC proportional to flow rates) or digital (pulse rate proportional to flow rate) outputs. Digital panel meters to read totalized flow (counter) or flow rate (digital voltmeter calibrated in gph) are optional at extra cost.

SPECIFICATIONS:

Characteristics	Model		
	LFM - 1.5 (A) or (D)	LFM - 15 (A) or (D)	LFM - 150 (A) or (D)
Range, lph (gph)	0.39-5.68 (0.1-1.5)	3.79-56.77 (1-15)	37.85-567.75 (10-150)
Power	115 VAC, 1Ø, 60 Hz	Same	Same
Dimensions (W,H,L), cm (in)	17.8x17.8x25.4 (7"x7"x10")	17.8x17.8x25.4 (7"x7"x10")	30x30x35 (12"x12"x14")
Tubing Connections, cm (in)	0.64 (1/4")	0.64 (1/4")	0.3 1.23 (1/2")
Max. System Temperature, C (F)	(150°F)	Same	Same

PRICE: $1,000 (approx.) and up.

COMMENTS:

This is a very ingenious device, but its application to wastewater flows must be considered limited due to its small capacity and potential problems with suspended solids, among other reasons.

MANUFACTURER: BADGER METER, INC.
INSTRUMENT DIVISION
4545 WEST BROWN DEER ROAD
MILWAUKEE, WISCONSIN 53223
TELEPHONE (414) 355-0400

PRODUCT LINE:

PRIMARY DEVICES - FLOW TUBES, NOZZLES, PARSHALL FLUMES

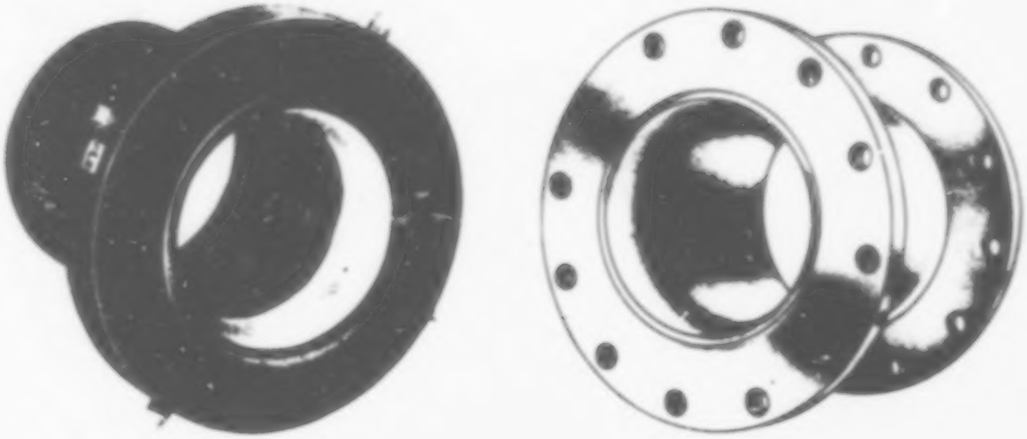
SECONDARY DEVICES - METER TRANSMITTER, ELECTRONIC RECEIVERS

DESCRIPTION:

The Water Meter Division of Badger has manufactured nutating disc type water meters for a number of years. However, because of the total unsuitability of such devices for raw sewage, they will not be included in this discussion.

Primary Devices

Flow Tubes - The Instrument Division offers, as primary elements, the proprietary "Lo-Loss" flow tubes. These tubes are available in a wide choice of designs, materials, and sizes and may find some application in wastewater flow measurement. Figure A shows typical "Lo-Loss" designs.



PLASTIC **CAST IRON**

Figure A

The chief advantage of the "Lo-Loss" design is its extremely low head loss (claimed to be the lowest of any primary element) even as compared to a long form Venturi tube. Unrecovered pressure loss as a percent of differential seldom exceeds 6%, and values of 3% are quite common. The available models include both full flanged and insert designs. Types PMT and PMT-U have manual vent cleaners for measuring sewage or slurries. Type PMT-S is a single-tap, full-flanged model design for sewage, sludge, or fluid high in suspended solids. Available designs are shown in Figure B.

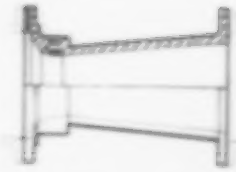
Open Flow Nozzles, Parshall Flumes - Badger Meter Inc. also offers open flow nozzles and Parshall flumes as primary devices.

Secondary Devices

Transmitter - The ML-MN transmitter (Figure C) is a secondary device designed for open channel flow head measurement. As flow varies, the transmitter's in-stream float senses the changing liquid level in the primary flow device. Through a single link from a stainless steel main shaft, the float's motion is relayed directly to core which moves vertically within the transmitting coil. The coil emits a signal voltage in direct relation to the core position. This signal is transmitted to the electronic receiver as discussed in the description of the electronic receiver.

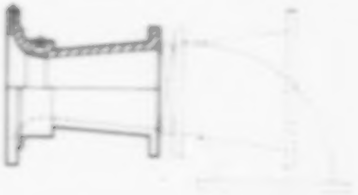
Advantages of this device, when compared to float-cable instruments which require stilling wells, are reported to be as the following:

- INSTALLATION ECONOMY...Excavation and concrete pouring for meter chambers are minimized. Stilling well and complex piping eliminated.
- MAINTENANCE ECONOMY..Clear water purge, routine cleanouts, cables, and counter weights also eliminated.
- ACCURACY CHECK...A mechanical position reference is furnished as standard equipment to provide a quick, positive calibration check.
- APPLICATION VERSATILITY...ML-MN transmitter and electronic receiver can be used with Badger Meter open flow nozzles, Parshall flumes, and weirs. Accurate response is also assured with Palmer-Bowlus flumes, standing wave flumes, and any other device for which the head-discharge relationship has been established up to a float travel of 0.8m (32 in.).



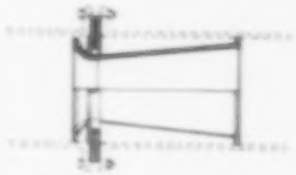
TYPE PMT: FULL FLANGED CAST IRON

This cast iron tube has a bronze-lined throat in which the averaging annulus is accurately machined with the body. Stainless steel throat also available. Manual vent cleaners provided for sewage, slurries or other fluids with suspended solids.



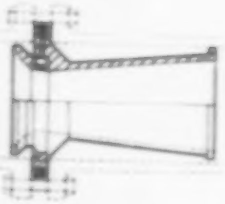
TYPE PMT-C: "CONTROLLER" TUBE

This model is similar to Type PMT except that it will accommodate a valve immediately downstream for rate-of-flow control. Outlet flange may be smaller than line size to permit a smaller valve. A standard increasing elbow or increaser is used to return to full line size.



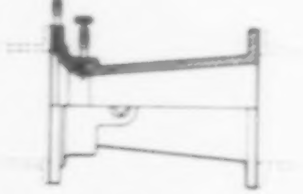
TYPE PMT-IF: FABRICATED INSERT

Designed primarily for clear fluids, Type PMT-IF is available in a variety of materials to suit specific applications. Can be supplied in carbon or stainless steel, aluminum, chrome-moly and other metals. Pressure connections are conveniently located in mounting flange.



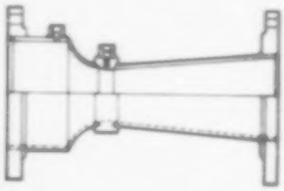
TYPE PMT-I: PLASTIC INSERT

The polyester-fibreglass body, tapped holding flange, and throat with internal annulus are molded as an integral unit. Throat and mounting flange are available in a variety of materials. Suitable for liquids and gases up to 200° F. Minimum operating temperature minus 20° F.



TYPE PMT-S: SINGLE TAP, FULL FLANGED

Designed for sewage, sludge or fluids with suspended solids. This tube has single taps for the high pressure and for the low pressure connections. Each tap is equipped with manual vent cleaner to permit periodic cleaning.



TYPE PMT-U: FABRICATED FULL FLANGED

This Lo-Loss tube offers wide flexibility in materials and design. An economical buy, particularly in the larger sizes. Can be supplied with single or multiple taps. Also available with manual vent cleaners for measuring sewage or slurries.

Figure B

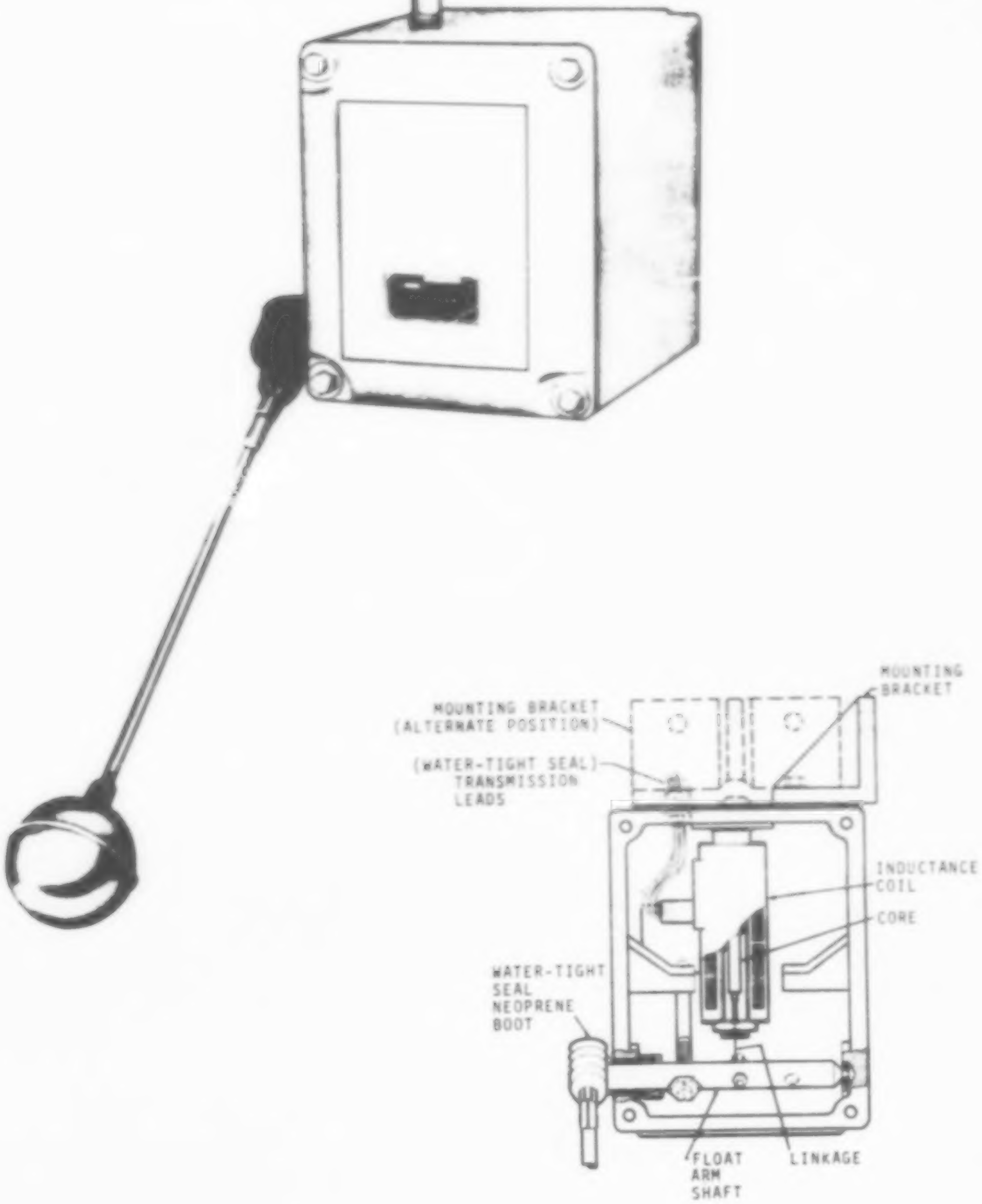

MOUNTING BRACKET (ALTERNATE POSITION)
MOUNTING BRACKET
(WATER-TIGHT SEAL) TRANSMISSION LEADS
INDUCTANCE COIL
CORE
WATER-TIGHT SEAL NEOPRENE BOOT
FLOAT ARM SHAFT
LINKAGE

Figure C

Electronic Receiver - The Badger Meter Inc. 2700 Series electronic receiver (Figure D) is connected to the transmitter (Figure C) by three transmission lines (Figure E), and power (110 VAC, 60 Hz) is applied only to the receiver. An actuating signal or error voltage is produced by the movement of the transmitting core within its coil which unbalances the electrical bridge. This signal is amplified to drive a two-phase, reversible servo motor which runs at a speed proportional to the error signal and in a direction established by the phase. Rotation of the motor repositions the core in the receiving coil and reduces the error signal to zero. As a result, the electrical bridge is restored to a null-balance condition. The pen, indicator pointer, and totalizer mechanisms are positioned simultaneously when the system is in balance; thus there is no time delay for recycling.

Receiver Style 2701 serves the combined functions of a recording, indicating, and totalizing instrument; Style 2705 is used as a remote indicator only.

As reported by Badger Meter Inc., the 2700 series electronic receiver can be used with a variety of transmitters for the measurement of flow, level, pressure, or temperature. For the convenience of the operator, the receiver can be located up to 5000 feet away from the transmitter without impairing calibrated accuracy (±1% of actual value being measured over the range specified for the transmitter) or speed of response. A selection of 30.5 cm (12 in.) diameter charts, with either 24-hour or 7-day rotation, can be made from more than 500 standards available.

SPECIFICATIONS:

Primary Devices

- The laying length of a typical "Lo-Loss" flow tube is roughly 2.5 times the pipe diameter. Stock units are available for pipe diameters ranging from 7.6 to 121.9 cm (3 to 48 in.), and other sizes can be obtained upon request.
- Bronze, carbon or stainless steel, aluminum, chrome-moly, and polyester-fiberglass are among the available construction materials.
- Standard accuracies of ±1% are claimed (or ±0.25% when laboratory calibrated).
- Ranges (see comparative rangeability of Figure F) of 20:1 are common, and even at 50:1, the meter coefficient deviation is only 2%.

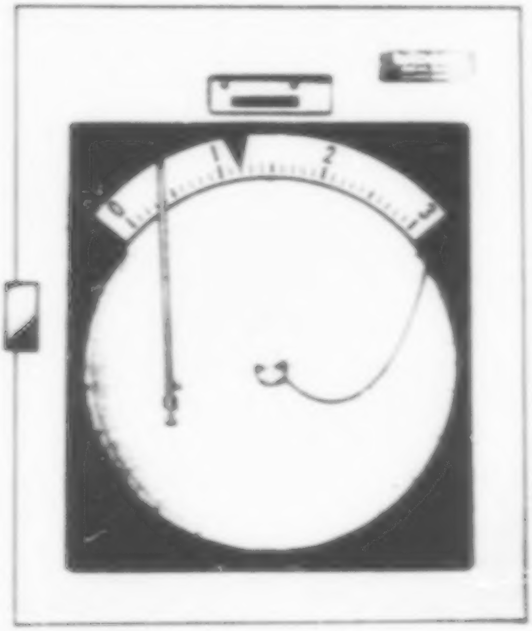


Figure D

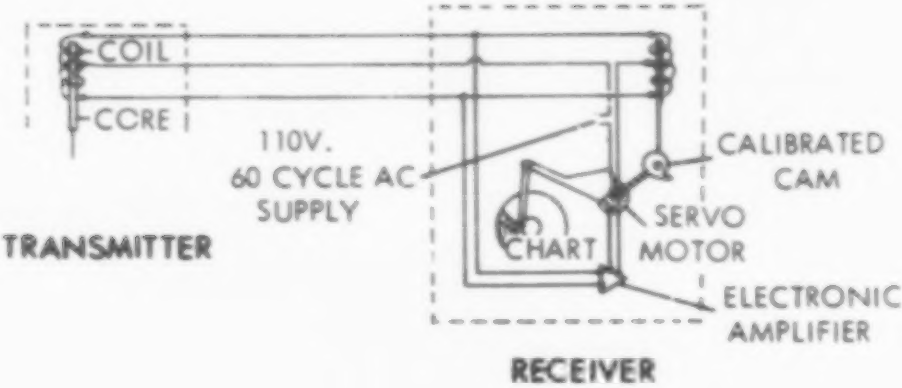

COIL
CORE
110V.
60 CYCLE AC
SUPPLY
TRANSMITTER
CALIBRATED
CAM
SERVO
MOTOR
CHART
ELECTRONIC
AMPLIFIER
RECEIVER

Figure E

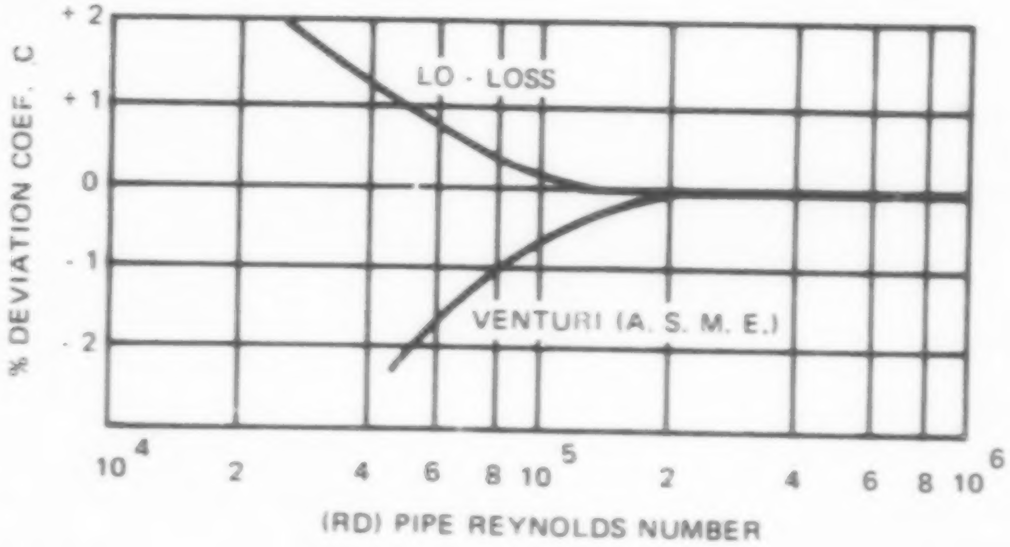


Figure F

Secondary Devices

	ML-MN Transmitter	2700 Series Receiver
Range	10:1 (20:1 available for extra cost)	N/A
Dimensions, (W, H, L)	25.8cm x 25.4cm x 32.4cm (10-3/16in x 10in x 12-11/16in)	22.2cm x 39.1cm x 48.9cm (8-13/16in x 15-5/8in x 19-3/16in)
Power	N/A	110 VAC, 60 Hz
Response Time	N/A	8 sec. (0 to Full Scale)

PRICE:

Primary Devices

"Lo-Loss" Flow Tubes	3 in. -	$ 716.00
	48 in. -	11,700.00

Open Flow Nozzles	6 in.	-	$ 640.00
	24 in.	-	3,900.00
Parshall Flumes	3 in.	-	280.00
	24 in.	-	1,565.00

Secondary Devices

ML-MN Transmitter/2700 Series Electronic Receiver	$ 1,150.00

COMMENTS:

Primary Devices

Where pressurized flow is always present, the "Lo-Loss" flow tube could prove to be a useful primary device for measuring storm or combined sewer flows at fixed installations, if proper attention is paid to the secondary element to avoid clogging problems.

The other primary devices offered by Badger (open flow nozzles and Parshall flumes) were thoroughly discussed in Section VI and will not be commented upon further here.

Secondary Devices

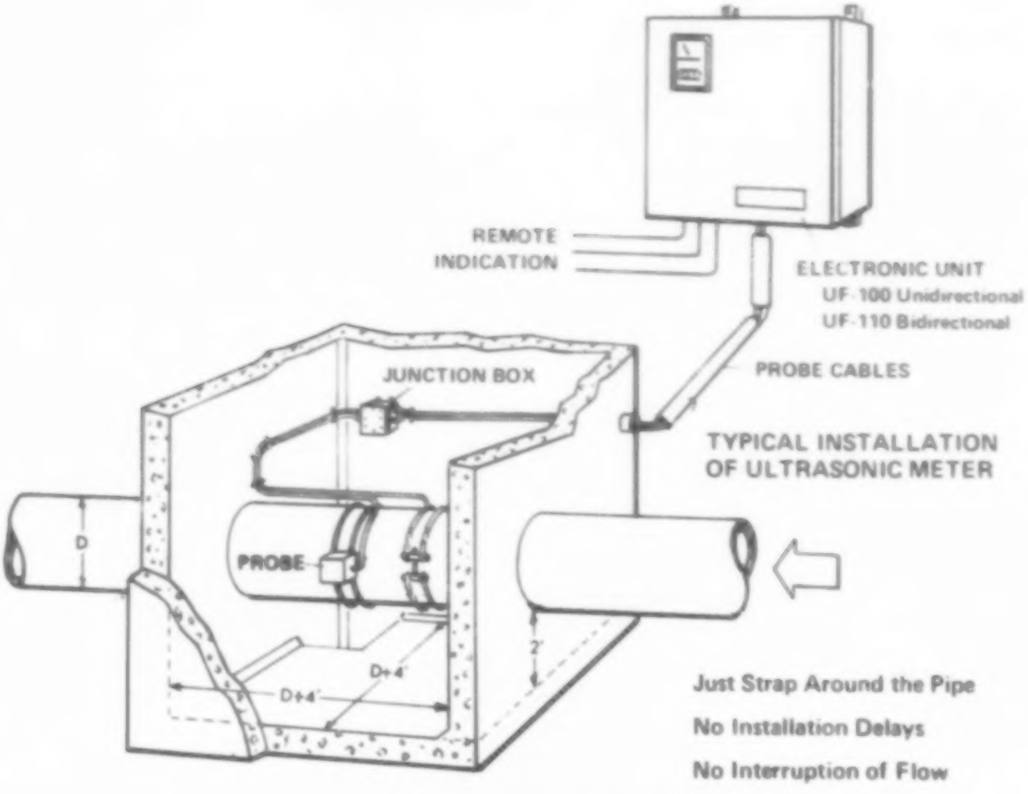
The ML-MN transmitter will withstand submergence, even though it will no longer operate because the float is off scale. Its 0.8-meter (32-inch) float travel allows it to be used with many primary devices. As with any float-in-flow secondary device, it suffers from the possibility of fouling (or even physical damage) from floating debris. The electronic sensing system offers advantages over more cumbersome cable and counterweight designs.

MANUFACTURER: BADGER METER, INC.
PRECISION PRODUCTS DIVISION
6116 EAST 15TH STREET
TULSA, OKLAHOMA 74115
TELEPHONE (918) 836-4631

PRODUCT LINE: ULTRASONIC FLOWMETER;
ULTRASONIC TRANSMITTER

DESCRIPTION:

Badger Meter, Inc. has entered into a cooperative agreement with Tokyo Keiki Seizosho Company, LTD. of Japan to market (within the United States) the ultrasonic flowmeter developed by the latter company. There are essentially three devices offered, and sales are through the Precision Products Division. A typical ultrasonic meter installation for full pipe flow is shown in Figure A.


REMOTE
INDICATION
ELECTRONIC UNIT
UF-100 Unidirectional
UF-110 Bidirectional
PROBE CABLES
JUNCTION BOX
TYPICAL INSTALLATION
OF ULTRASONIC METER
D
PROBE
2'
D+4'
D+4'

Just Strap Around the Pipe

No Installation Delays

No Interruption of Flow

No Parts in the Stream

Figure A

The ultrasonic flowmeter uses the propagation of ultrasonic energy across a fluid stream to determine flow velocity. These devices are designed for metering raw and treated sewage and wastewaters; also, many industrial fluids can be metered.

Model UF-100 (Unidirectional) and UF-110 (Bidirectional) Flowmeters - These are complete ultrasonic flowmeters for measuring full flow in pipe sizes of 0.3m (1 ft) and larger. These devices employ a pair of ultrasonic velocity probes that are strapped to the outside of the pipe wall. A clearance area measuring at least 1.2m (4 ft) greater than the pipe diameter in each dimension is required. The device can be installed in existing as well as new construction and produces no head loss since there is nothing inside the pipeline. The velocity probes utilize the "sing-around" principle* to measure average fluid velocity within the pipe which is combined with pipe cross-sectional area to produce an output signal (4-20 mADC) proportional to flow. A wide selection of 30.5 cm (12 in.) diameter charts is available with either 24-hour or 7-day rotation. A totalizer option is also available.

Model UF 310A Flowmeter - This model is a complete open channel ultrasonic flowmeter that does not require the use of a weir, flume, or other pre-rated structure. It employs a pair of ultrasonic velocity probes and combines their output with flow depth as measured by an ultrasonic depth probe (essentially the probe of Model UH 200) and channel cross-section to produce an output signal (4-20 mADC) proportional to flow. The device can be installed in existing as well as new construction and will produce little or no head loss since, at most, only the small velocity probes need be in the flow. As with the Models UF-100 and UF-110, the velocity probes operate using the "sing-around" principle. Channel shapes can be either circular, rectangular, trapezoidal, or elliptical. As shown in Figure B, the velocity probes are generally mounted in, or attached to, the channel walls at about 25% of maximum depth. A wide selection of charts (identical to those for Models UF-100/110) is available, as is a totalizer option and bidirectional capability. The three probes, which together weigh 38.6 kg (85 lbs), may be located up to 305m (1000 ft) from the electronics box, which is a small wall-mounted unit weighing 68 kg (150 lbs).

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* Each received sonic pulse triggers the transmission of another pulse across the flow stream in a "sing-around" fashion. The number of such pulses occurring in a one-second period is called the sing-around frequency.

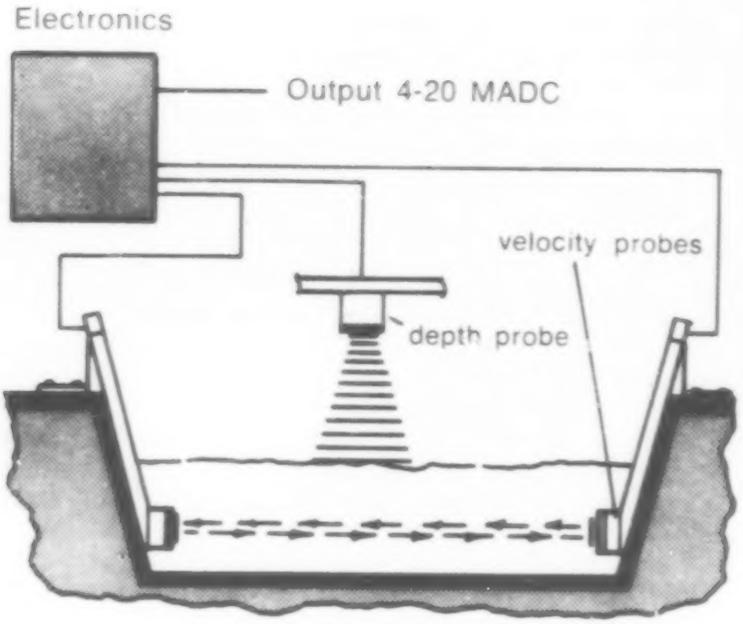
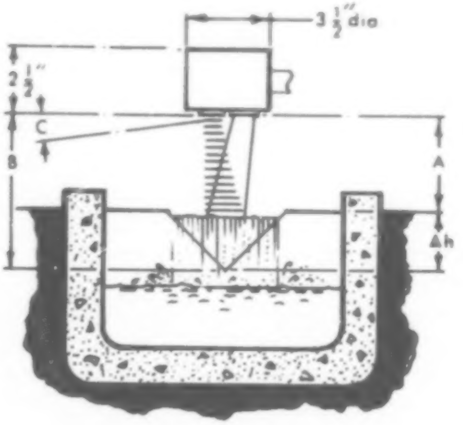


Figure B

Model UH 200 or UH 210 Ultrasonic Flow Transmitter - This equipment has an output signal proportional to level (UH 200) or flow (UH 210) and serves as a secondary element for level and flow indicating, recording, and totalizing measurements in flumes, weirs, or other open channel primary elements. The device employs an ultrasonic probe set in a common head. The acoustic signal is transmitted to the fluid surface (see Figure C), and the elapsed travel time for the reflected signals' return is converted into fluid depth. As the level of the fluid



INSTALLATION

A. Transmitter shall be placed at least 6" above maximum level not to exceed the Δh above maximum level (i.e. Δh min. = 6")

B. Total transmission length shall not exceed 10' 6"

C. The horizontal plane across the face of the probe shall be level to within ± 2"

Figure C

surfaces changes, the UH 200 produces a proportional signal (4-20 mADC). Model UH 210 incorporates a digital function generator which allows direct and continuous conversion of the fluid level signal to any specified depth-discharge relationship. This can be changed in the field to allow use with different primary elements. A wide variety of 30.5 cm (12 in.) diameter charts is available with either 24-hour or 7-day rotation.

SPECIFICATIONS:

	Model		
Characteristic	UF-100 and 110	UH-200 and 210	UF-310A
Resolution	±1% of Full Scale	±1/4% of Full Scale	±1% of Full Scale
Accuracy	±1% of Full Scale	±2% of Full Scale	±3% of Full Scale
Output			
Analog	4-20 mADC into 1000Ω	Same	Same
Time Pulse	3-9-3 (15 sec. period)	N/A	N/A
Digital	48V Pulse (Train Scaled)	N/A	N/A
Probe Cable Length	Up to 305 meters (1000 ft)	Same	Same
Power	115 VAC, 60 Hz, 3A	Same	Same
Dimensions			
Electronics	57 x 64 x 30 cm (22.44x25.20x11.81 in)	22.7 x 13.7 x 34.3 cm (10-1/2x5-3/8x13-1/2 in)	
Junction Box	8.4 x 18 x 20 cm (3.3x7.1x7.9 in)	N/A	N/A
Probe(s)	12.4 x 15.0 x 18.3 cm) (4.9x5.9x7.2 in)	8.9 cm (3.5 in) Dia. X 6.4 cm (2.5 in) High	
Weight			
Electronics	54 kg (119 lbs)	7.3 kg (16 lbs)	
Junction Box	2.5 kg (6 lbs)	N/A	N/A
Probe	16.8 kg (37 lbs)(2)	1.8 kg (4 lbs)(1)	38.6 kg (85 lbs)(3)

PRICE: Models UF-100 and UH-110 start at about $1,000

Model UF-310A starts at about $3,000

Models UH 200 and UH-210 start at about $3,000

COMMENTS:

These ultrasonic flow measurement devices have performed fairly well in their somewhat limited (up until now) use in this country. Models UF-310A and the UH series are especially well suited for storm and combined sewer flow measurement. There have been some reports of problems due to echos or false returns from the UH series probes. Some field workers have put a short piece of plastic pipe over the head and obtained improved results.

MANUFACTURER: BIF - A UNIT OF GENERAL SIGNAL
1600 DIVISION ROAD
WEST WARWICK, R.I. 02893
TELEPHONE (401) 885-1000

PRODUCT LINE:

PRIMARY DEVICES - PARSHALL FLUME LINERS, VENTURI TUBES AND NOZZLES, DALL FLOW TUBES, KENNISON OPEN FLOW NOZZLES

SECONDARY DEVICES - "CHRONOFLO" TRANSMITTER AND RECEIVER UNITS, PRESSURF SENSORS, TOTALIZERS, AND INDICATORS

DESCRIPTION:

BIF, a unit of General Signal Corporation, has been active in the water flow measuring field for over 100 years. Their primary flow measuring products include such devices as Parshall flume liners, the recently developed Universal venturi tube which has largely replaced their Dall flow tubes, and Kennison open flow nozzles. BIF also offers the Solids Bearing Fluids (SBF) Flowmetering System, which is reported to provide precise, highly sensitive detection of differential pressures created by Universal Venturi Tubes when the measured fluid is high in suspended solids.

BIF's secondary units are represented by several Chronoflo transmitter and receiver units for indicating flow depths in primary devices.

Parshall Flume Liners - BIF's precision-molded, one-piece plastic Parshall flume liner, Model 141, is said to accurately duplicate Parshall flume proportions. It is light-weight and can be easily installed without the aid of a crane or special tools; there are also no seams requiring special cements or sealing compounds. BIF plastic Parshall flume liner Model 141 is available in throat width sizes ranging from 7.62 cm (3 in.) to 2.44m (8 ft) to accommodate flcw rates ranging from 75.7 kld (.02 mgd) to 341,255 kld (90.16 mgd). Parshall flumes were throughly treated in Section VI and will not be discussed further here.

Universal Venturi Tube - BIF has developed a proprietary, differential-pressure primary device that combines the metering performance of the classical venturi tube with some of the more desirable features of differential pressure devices such as the Dall flow tube. It offers extremely short laying lengths (less than half that of a short form classical venturi tube), a great magnification of the differential pressure signal (about twice that of classical venturis), and low permanent head loss (almost as little as a Dall tube). The advantages offered by the Universal Venturi Tube are due to its unique hydraulic design, especially from the inlet to the throat tap (see Figure A), that "conditions" the flow by creating a consistent artificial turbulence in the throat flow pattern so that readings are stable and predictable. No blending radii are used, so flow separation and stream-line bending are employed as in the Dall tube.

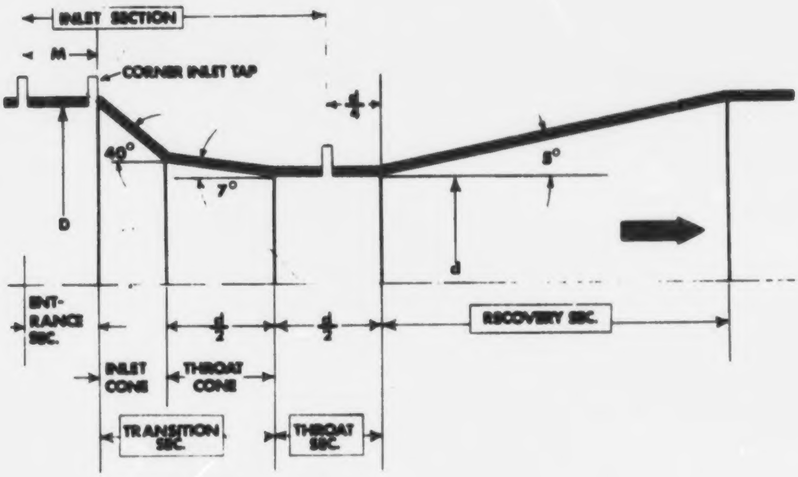


Figure A

The Universal Venturi Tube is available in line sizes from 2.5cm (1 in.) to 1.2m (4 ft) as stock and up to 2.4m (8 ft) on special order. Even larger units can be made on request. Series 180 Universal Venturi Tubes are available as insert types or flanged types. Standard tubes have cast iron bodies and bronze throats with the cast iron surfaces (both interior and exterior) finished with tar or Bitumastic paint. A large variety of other materials are available in weldment form, and fiberglass reinforced plastic insert types are also standard construction.

The tube coefficient is virtually independent of the Beta ratio (ratio between throat and inlet diameters), the pipe Reynolds number (above about 50,000), and line sizes. There is virtually no installation effect caused by upstream piping configurations, and downstream piping causes no effect whatsoever. As a result, uncalibrated accuracies of ±0.75% can be guaranteed and, with calibration, ±0.25% is achievable. Standard ranges are around 5:1.

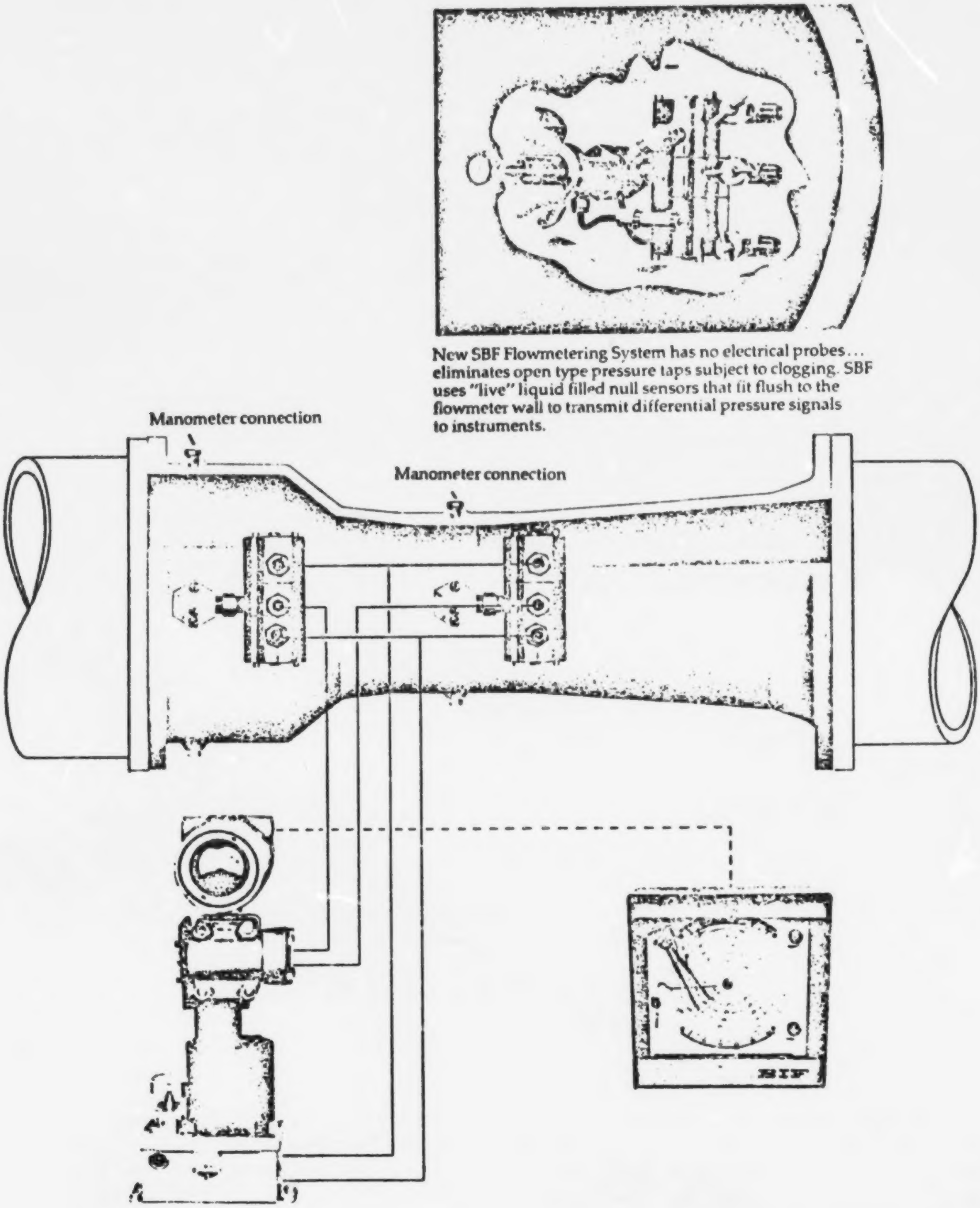
Kennison Open Flow Nozzle - This open flow nozzle is a simple device for measuring flows through partially filled pipes. The nozzle handles low flow and wide flow ranges with ease. Because of its high accuracy, non-clogging design and excellent head versus flow characteristics, the Kennison nozzle is well suited for the measurement of raw sewage, raw and digested sludge, final effluent, and trade wastes. The Kennison Nozzle is constructed of high tensile cast iron. The piezometer vent opening is bushed in brass and is equipped with a bronze-mounted manual vent cleaner. Hydraulically-operated vent cleaning can also be used where the nozzle is installed in inaccessible places. The nozzle is available in inlet diameters of 15.2 to 91.4 cm (6 to 36 in.) and will accommodate flows of 340 to 53,000 ℓpm (90 to 14,000 gpm).

Uncalibrated accuracies of ±2% for a range of 10:1, ±3% for a range of 15:1, and ±5% for a range of 20:1 have been demonstrated. Special laboratory calibration will assure accuracy within ±1% of actual flow for a range of 20:1. A Kenniflo rate indicator is available for use with the nozzle to provide visual evidence of instantaneous rate of flow. This indicator can be graduated in gpd, gpm, or mgd as well as inches of head.

Solids Bearing Fluid Flowmetering System (SBF) - As shown in Figure B, the SBF system is built around a combination of components -- the primary element, a Universal Venturi Tube Model 185 (UVT) (center); two pressure sensing probes (upper right); and a differential pressure transmitter (lower left). All of these components may be purchased individually. Claims made for this system include:

- No electrical components are in contact with line fluid.
- Water purging is eliminated.
- No circuit fouling or drift occurs.
- Instrumentation lines cannot be fouled by solids or entrained gases.
- System is unaffected by changes in static line pressure.
- Sensors can be removed while line is in service.
- System provides highly sensitive detection of flow signals produced by the venturi tube.
- All readings can be verified by a simple manometer.

The above is accomplished by the direct one-to-one transfer of pressure through a limp diaphragm which is held at a precise null position, regardless of the magnitude of the measured pressure, by a pure silicon fluid pressurized by a miniature hydraulic gear pump. The liquid is delivered continuously through a filter to the probes at a pressure consistent with line pressure, and exhaust fluid is fed back to the



New SBF Flowmetering System has no electrical probes... eliminates open type pressure taps subject to clogging. SBF uses "live" liquid filled null sensors that fit flush to the flowmeter wall to transmit differential pressure signals to instruments.

Manometer connection
Manometer connection
BIF

Figure B

pump reservoir. Due to the reset action provided by the supply-exhaust regulator unit associated with each probe, sensing diaphragm movement is limited to less than 0.03 mm (0.001 in.). The center button of the diaphragm carries one end of an armature, the other end of which is supported and centered by a spiral-spring bearing. The end of the armature acts as a baffle and floats close to the nozzle, regulating exhaust of the fluid from the probe to the exhaust pressure regulator. This probe system is highly responsive to rapid pressure changes, essentially behaving like a filled-and-sealed system.

Transmitter Units - BIF manufactures several secondary transmitter units. The Model 231-08 is a float actuated, free-standing, weatherproof Chronoflo transmitter-indicator mounted in a waterproof stand for level indication at its location. It also transmits readings to Chronoflo receivers for remote indicating and recording. The remote signal line requirements can be met by leased signal facilities equivalent to low frequency telegraph channel capable of repeating time-duration impulse closures or a private metallic pair with a maximum loop resistance not to exceed 2500 ohms.

The BIF Chronoflo Model 231-09, used for flow rate determination, is identical to the Model 231-08 in appearance, weight, and signal line and power requirements. Both are designed for stilling well operation.

The BIF Chronoflo Model 231-34 is an in-stream, float-operated electrical transmitter designed especially for use with head-area primary flow measuring elements such as Parshall flumes, Kennison nozzles, weirs, and other open flow primary devices. This transmitter operates with equal facility over telephone or teletype lines, telegraph circuits, private signal lines, tone or microwave links. The unit consists of the transmitter, indicator (optional extra), a spherical, truncated float manufactured of ABS plastic, and a nylon-coated, stainless steel float cable.

The Model 251-08 electronic differential pressure transmitter is a compact transducer designed to translate a differential pressure into a DC current signal and is designed to work with the SBF flow metering tubes only.

Miscellaneous - BIF also manufactures a line of pressure sensors and Chronoflo receivers, recorders, and summator/subtractor totalizer units for use with the primary and secondary units described above.

The SBF system's recording device is BIF's electronic receiver and is available in either strip or round chart, compact or full case models. The electronic receiver will accept both 4-20 mA and 1-5 volt signals.

SPECIFICATIONS:

Typical specifications for the BIF line of secondary flowmetering devices are as follows:

Model 231-08 Transmitter

Accuracy:	±0.5% for a range of 100:1
Dimensions:	143.5 cm (56-1/2 in.) height with a base dimension of 48-1/4 by 31 cm (19 x 12-1/4 in.).
Weight:	136 kg (300 lb).
Power:	115 VAC, 60 Hz @ 6 watts

Model 231-09 Transmitter

Standard Accuracy:	±0.5% of maximum rate.
Extended Accuracy:	±1% of actual reading.
Range:	10:1 for a maximum float travel of 12.7 cm (5 in.) to 30.48 cm (12 in.). 20:1 for maximum float travel of 30.48 cm (12 in.) to 76.2 cm (30 in.).

Model 231-34 Transmitter

Standard/Extended Accuracy:	±2%/0.5% of maximum instrument reading.
Range:	10:1 for maximum float travels from 12.7 to 30.5 cm (5 to 12 in.); 20:1 for maximum float travels over 30.5 cm (12 in.), except on applications with Parshall flumes or Kennison nozzles where head at maximum rate is less than 2.54 cm (1 in.) for maximum float travels up to 45.7 cm (18 in.), or 3.81 cm (1.5 in.) for maximum float travels over 45.7 cm (18 in.).
Dimensions:	Float - 15.24 cm (6 in.) dia. Float Cable - 0.09 cm (0.035 in.) dia.

Power: 115 VAC, 60 Hz, Single Phase

PRICES:

Standard prices not available at the time of this writing.

COMMENTS:

Parshall flumes and Kennison open flow nozzles were discussed fully in Section VI and will not be commented upon further here. The Universal Venturi Tube would appear to be one of the better differential-pressure type primary devices for use with sewage. Its requirements for full pipe flow and small range (5:1) may limit its application, however. The pressure probes used in the SBS would seem useful for other differential-pressure devices and can be purchased separately. They could be used with existing differential pressure devices where line plugging or other problems have been high and maintenance troublesome.

MANUFACTURER:	BRAINCON CORPORATION A COMPANY OF TALLEY INDUSTRIES, INC. MARION, MASSACHUSETTS 02738 TELEPHONE (617) 748-1085
PRODUCT LINE:	CURRENT METERS

DESCRIPTION:

The Braincon Corporation produces two basic types of primary current meters. The type 381 and 1381 Histogram current meters utilize 2/3 and full size Savonius rotors, respectively, and record current rates on 16 mm film by taking time exposures of radio-luminous sensor indicators. Braincon maintains complete processing and data translation facilities. These current meters will not be discussed further since application in the measurement of wastewater flow rates is inappropriate.

Braincon has developed a Model 720 electromagnetic current meter that is capable of monitoring flows between 0 to 2 m/s (6.6 fps). It uses an orthogonal array of four electrodes in the sensor head to present instantaneous readings of the N-S, E-W components of the flow. The output voltage varies linearly with the velocity of the fluid flow over the sensor head. The Model 720 meter utilizes an oblate ellipsoidal form (discus) probe that efficiently preserves laminar flow over a generous range of adverse conditions. Of interest is its superior performance improvement over historically accepted mechanical transducers such as the Savonius rotor. Also noteworthy are the total freedom from any mechanical designs; the use of a solid state fluxgate magnetometer rather than a conventional compass; its high resistance to fouling; lower meaningful measuring thresholds; the use of Cartesian coordinates rather than polar; instantaneous readout of N-S, E-W vector components; high sensitivity to the physical environment; a faithful cosine response; and less application dependency in critical wave-zone effect areas.

The 720 current meter can be used with a variety of readout devices if the proper interface is provided. Lengths of electrical cable up to approximately 30m (100 ft) are provided as standard equipment with the Model 720, with additional lengths available.

SPECIFICATIONS:

Output:	±2 VDC full scale (other ranges available)
Accuracy:	±1.5 cm (0.6 in.)/sec or 2% of full scale
Threshold:	< 2 cm (0.78 in.)/sec

Resolution: 0.5 cm (0.2 in.)/sec

Power: 24 ± 4 VDC

Operating Temperature: -2°C (28°F) to 40°C (104°F)

Length: 107.6 cm (42.35 in.)

Diameter: 20.3 cm (8 in.), maximum

Weight: 23 kg (50 lb)

PRICE: Standard surface readout model: $5,000

Deep-water, long-term implant model: $8,000

COMMENTS:

This electromagnetic current meter was designed for oceanographic applications, but may find some use as a portable current meter for attended operation in measuring wastewater flows. Its low upper velocity limit will severely restrict its use, however.

MANUFACTURER: BROOKS INSTRUMENT DIVISION
EMERSON ELECTRIC COMPANY
407 WEST VINE STREET
HATFIELD, PENNSYLVANIA 19440
TELEPHONE (215) 247-2366

PRODUCT LINE: VARIABLE-AREA FLOWMETERS, TURBINE FLOWMETERS, POSITIVE DISPLACEMENT FLOWMETERS PROPELLER METERS, LIQUID LEVEL INSTRUMENTS, ELECTROMAGNETIC FLOWMETERS, ETC.

DESCRIPTION:

Brooks manufactures a complete line of glass and metal metering tube variable-area flowmeters (rotameters) in sizes to 12,000 ℓ/m (3,200 gpm) and priced from $50 to $6,000. A number of pneumatic or electric transmitters, receivers, alarms, etc., are available as accessories. None of these is considered suitable for wastewater flow measurement and, consequently, no further discussion of them will be given.

Primary Devices

Brooks turbine flowmeters are manufactured in six different series for use in various types of service, including chemical, cryogenic, aircraft fueling, and petroleum pipelines, etc. Ranges of 10:1 are standard, and accuracies as great as ±0.15% (with repeatability within 0.015%) are available with the Series M viscosity-compensated turbine meters. Prices range from $340 to $13,800. Brooks also offers a complete line of accessories including indicators, totalizers, printers, etc.

Brooks manufactures nutating disc, oval gear, oscillating piston, and bi-rotor type positive displacement meters in various models and sizes, all of which are designed for clean fluid service only. The same is true of their bulk water propeller meters. Since their application to wastewater flows is not recommended, they will not be described further.

The Series 7100-7200 electromagnetic flow transmitters manufactured by Brooks are solid state flow rate sensing elements. A typical unit is depicted in Figure A. They are designed to withstand tough service applications such as corrosive, humid and dirty environmental conditions, wide variations in temperatures, and high vibration loads. All adjustments are precise and are made externally; once set, there is no change. The three-electrode design is immune to changes in conductivity of the metered liquid. The transmitter utilizes an integral FET type preamplifier (impedance converter) to provide a low impedance output signal to permit long lengths of interconnecting cables without

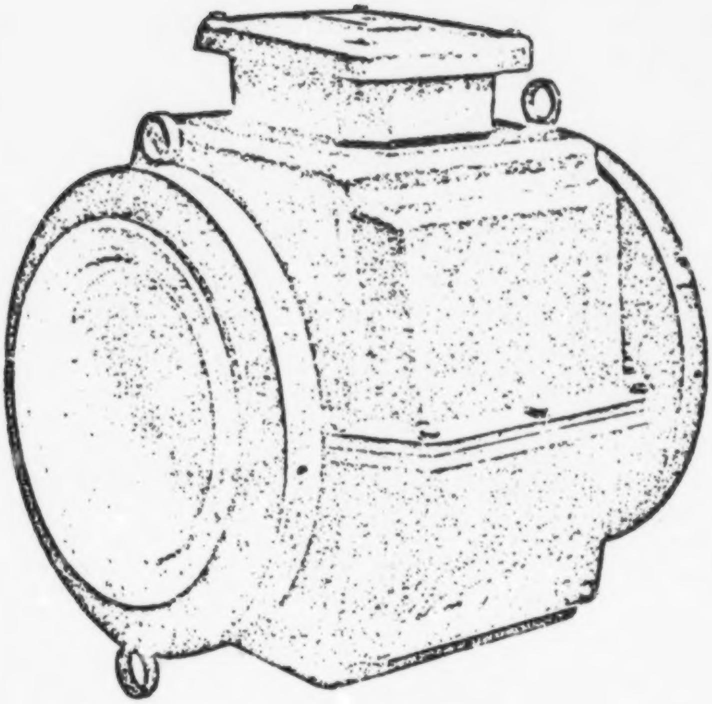


Figure A

regard to liquid conductivity or adverse effects of noise pickup. Brooks-Mag transmitters, in conjunction with Brooks-Mag signal converters, provide output signals which are compatible with almost any manufacturer's secondary equipment. Electromagnetic transmitters and signal converters are fully interchangeable and are adjusted and calibrated independently of each other. The transmitter uses a potentiometer to adjust a reference voltage whose ratio to the signal voltage is constant in all transmitters regardless of size, materials of construction, and liquid being metered. Signal converters are always adjusted to identical input values.

Standard meter sizes are from 0.25 cm (0.1 in.) to 1.2m (4 ft), and units up to 2.4m (8 ft) are available on special order. Normal velocity ranges are 0 to 9 m/s (30 fps), and standard accuracy is ±0.5% of full scale over the entire flow range. The design features a short laying length; e.g., a 61-cm (24-in.) diameter meter is only 76 cm (30 in.) long. Type 304 stainless steel is the standard metering tube material, and various line materials such as neoprene, gum rubber, polyurethane, etc., are available. Among the units other design features are:

- LOW POWER CONSUMPTION - yet has high signal-to-noise ratio; can operate empty with power on.
- LOW INSTALLATION COST - only a single conduit between transmitter and signal converter.
- SEALED METER HOUSING - weather resistant-protects coils which are mounted (for easy serviceability) on outside of flow tube. Meets NEMA 4 specifications. Submersible design optional.
- POSITIVE ZERO RETURN - optional zero level locking circuit actuated by remote contact. Holds output signal at zero flow rate value.
- UNAFFECTED BY CHANGES - in conductivity, temperature, pressure, density, and viscosity.
- ADJUSTABLE FLOW RANGES - full scale deflection can be easily set for any flow rate within the limits of the transmitter.
- IMMUNITY TO STRAY VOLTAGES DUE TO UNIQUE ELECTRODE BALANCE SYSTEM - eliminates the need for adjustments.
- LONG CABLE LENGTH - distance between transmitter and signal converter is not limited by the conductivity of the liquid.
- ELECTRODE CLEANERS - optional ultrasonic, or mechanical scraper in only complete line of cleaners available. Cleaners prevent accumulation of matter on transmitter electrodes which could affect metering accuracy.
- PROTECTIVE SHIELD/GROUNDING RING - (optional) prevents damage to meter lining materials when handling abrasive and solids-bearing liquids.

Where it is not desired to time-share one signal converter with several electromagnetic flow transmitters, Models 7700-7800 are available. These models are essentially a Model 7100-7200 flow transmitter with an integrally-mounted signal converter. Figure B depicts typical configurations.

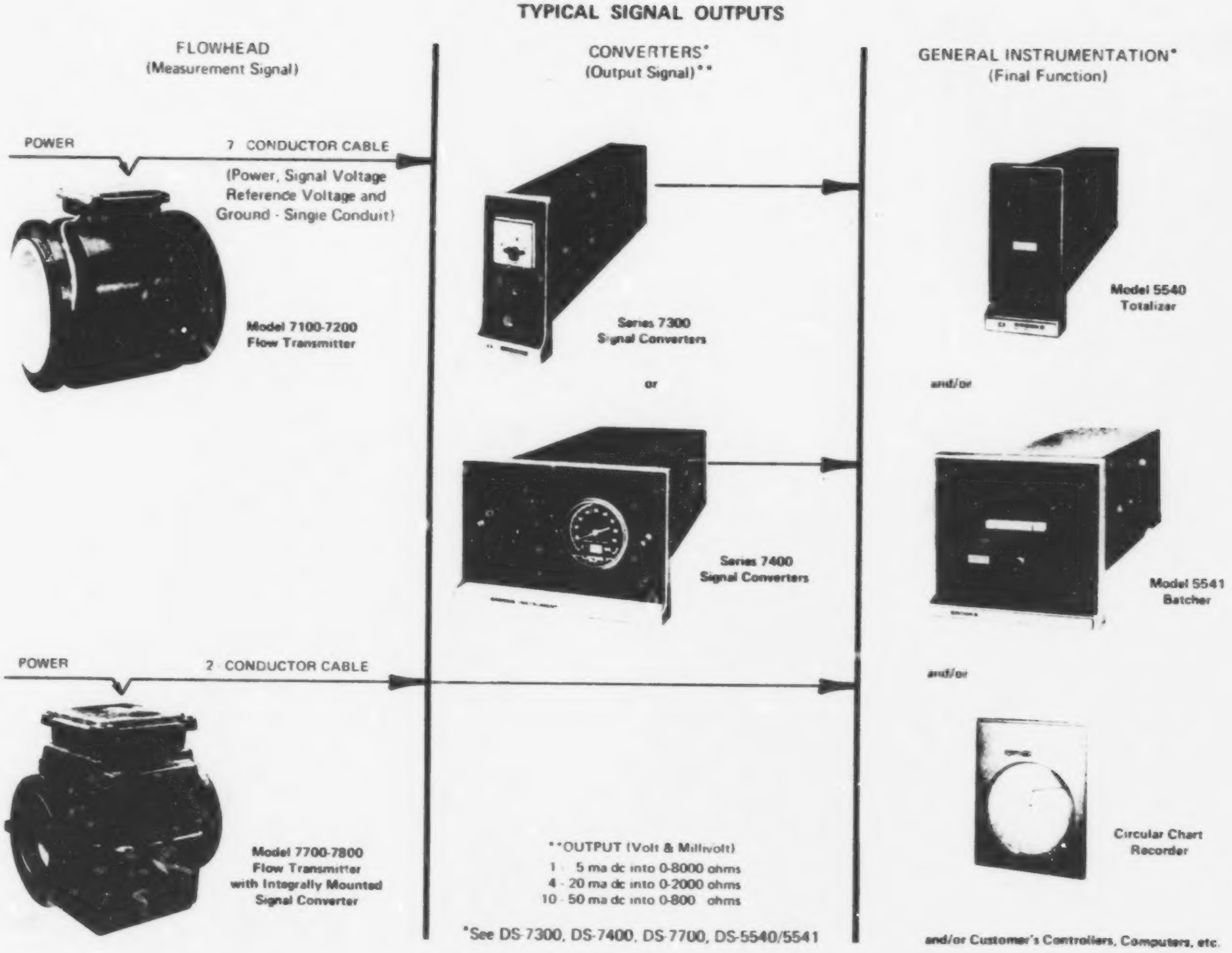

TYPICAL SIGNAL OUTPUTS
FLOWHEAD
(Measurement Signal)
CONVERTERS*
(Output Signal)**
GENERAL INSTRUMENTATION*
(Final Function)
POWER
7 CONDUCTOR CABLE
(Power, Signal Voltage Reference Voltage and Ground - Single Conduit)
Model 7100-7200 Flow Transmitter
Series 7300 Signal Converters
or
Series 7400 Signal Converters
Model 5540 Totalizer
and/or
Model 5541 Batcher
and/or
Circular Chart Recorder
POWER
2 CONDUCTOR CABLE
Model 7700-7800 Flow Transmitter with Integrally Mounted Signal Converter
**OUTPUT (Volt & Millivolt)
1 - 5 ma dc into 0-8000 ohms
4 - 20 ma dc into 0-2000 ohms
10 - 50 ma dc into 0-800 ohms
*See DS-7300, DS-7400, DS-7700, DS-5540/5541
and/or Customer's Controllers, Computers, etc.

Figure B

Secondary Devices

Signal Converters - Series 7300 Signal Converters are all solid state instruments which receive the electrical output signals that are linear with flow rate. There are no servo motors, balancing slidewire, or other components that can wear out. The Brooks Model 7300 Series Signal Converter amplifies and converts the AC output signal from the flowhead into a DC signal. Since the DC signal is directly proportional to the liquid flow rate, it is used to drive a meter on the signal converter that indicates percent of maximum flow. The DC signal can be adjusted for various operating ranges, and can be used with indicators, controllers, recorders, and systems that require direct current inputs for operation.

The AC flow rate signal from the flowhead is coupled into an impedance converter having an input impedance of approximately 2000 Mohms. The signal is amplified, converted to DC, and coupled to a divider. Similarly, the reference voltage from the flowhead is converted to DC, amplified, and coupled, in the proper sense, to the divider. A constant DC multiplier signal (factory pre-set) is coupled to the divider for scaling purposes. The specific function of the dividing feature is to produce a ratio between the signal and reference voltages for all specified flow rates. Fluctuations of primary power causes proportional fluctuations of both signal and reference voltages. Therefore, by maintaining the ratio constant for a given flow rate, the primary power fluctuations are ignored. The computed output signal is then conditioned as required and transmitted to the users receiving devices.

Series 7400 Signal Converters are all solid state devices which receive the electrical outputs from Brooks electromagnetic flowmeters and convert these outputs to useable electrical output signals that are linear with flow rate. The signal converters are integrated units of modular design capable of high system accuracy with a minimum of components. The Brooks Model 7400 Series Signal Converter amplifies and converts the AC output signal from the flowhead into a DC signal, or a pneumatic signal. Since the signal is directly proportional to the liquid flow rate, the meter on the signal converter directly indicates percent of maximum flow. The output signal can be adjusted for various operating ranges and can be used with indicators, controllers, recorders, and systems that require DC or pneumatic inputs for operation.

The electrical output from the electrodes in the flowmeter is amplified by a high impedance preamplifier. This signal is combined with a reference signal and then fed to a servo-amplifier which, in turn, powers a servo-motor. The servo-motor drives a totally enclosed slidewire to achieve a true null-balance by balancing a reference voltage (fed through the slidewire) against the signal voltage. In addition, the servo-motor operates the pointer which indicates flow rate, and also rotates the cam which actuates the pneumatic transmitter or integrator.

Design features common to both the Series 7300 and 7400 signal converters include:

- HIGH ACCURACY - Standard accuracy is ±0.5% full scale output.
- COMPLETE INTERCHANGEABILITY - All units interchangeable with each other and with other signal converters from Brooks.

SUMMARY OF 7400-SERIES SIGNAL CONVERTERS

Model Number	READOUT					
	Flowrate Indicator Dial	7-Digit Counter	Pneumatic Signal Output	Current Voltage Output	Output Resistance	Telemetry
7410	Yes	-	-	-	-	-
7411*	Yes	-	-	-	-	-
7430	Yes	Yes	-	-	-	-
7431	Yes	-	-	-	-	Yes
7450	Yes	-	Yes	-	-	-
7460	Yes	-	-	Yes	-	-
7470	Yes	Yes	Yes	-	-	-
7475	Yes	Yes	-	Yes	-	-
7490	Yes	-	-	-	Yes	-
7495	Yes	Yes	-	-	Yes	-

* 8-1/2 inch indicator dial

- LINE VOLTAGE COMPENSATION - Inherent compensation for line voltage variations.
- EMPTY PIPE ZERO - Output goes below zero when flowmeter electrodes are not exposed to conductive liquid (standard).

- MULTIPLEXING - One signal converter can be time shared with several flowmeters.

- LEAD LENGTH - Signal is not affected by lead length.

- MINIMUM INSTALLATION COST - Only one conduit is required between flowmeter and signal converter.

- MULTIPLE RANGE - Front-of-panel range selection available, or ten-turn potentiometer mounted on printed circuit board (optional).

- SERVICEABILITY - Chassis may be pulled out for inspection without shutting down flow or interrupting output.

- MOUNTING - Cases available for flush panel, wall or pipe-stand mounting. Cases available in standard, weather-proof, or explosion proof construction.

Continuous Level Measurement and Control Systems - The Brooks "Maglink" liquid level system was specially designed for use in pressurized tanks or in open vessels in chemical service, where severe conditions of corrosion, temperature, and pressure may occur. All parts in contact with the liquid are made from stainless steel, plastic, or special materials, thus enabling the equipment to be used for most applications in the chemical, food, and allied industries such as liquified gases, acids, etc. The "Maglink" magnetic system has a sufficiently strong coupling to withstand even the most severe fluctuations in liquid level within the tank. The unit is schematically illustrated in Figure C.

Any change in liquid level moves the float, which contains an annular magnet. The float traverses a sealed guide tube. The flux linkage between the float magnet and the tape magnet within the tube transmits the movement via the tape, to the indicating mechanism in the head. Backlash in the indicator mechanism is completely eliminated by means of a constant torque spring, which also serves as a take-up device for the tape and compensates for the weight of the magnet. The density of the liquid is accomodated by the range of floats available. Design features of the unit include:

- Sealed system - for pressure or vacuum service
- Materials of construction for corrosive service
- High accuracy
- No calibration required

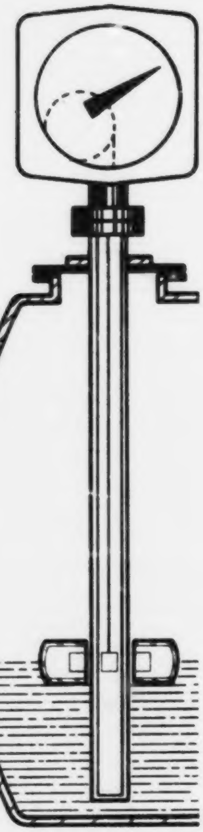


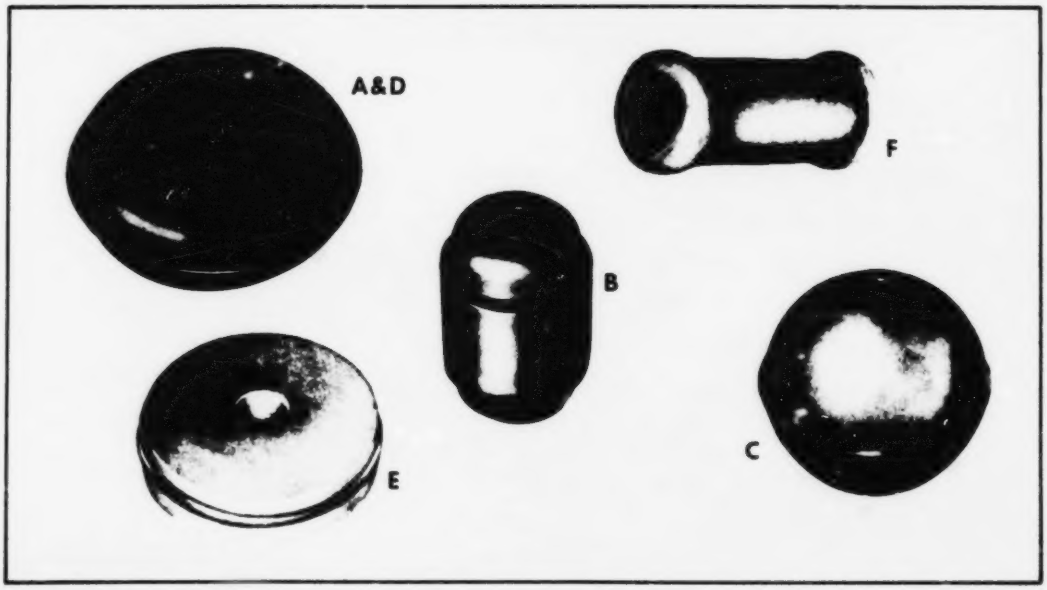
Figure C

- Remote transmission, pneumatic or electric
- Good readability - 25.4 cm (10 in.) direct reading dial
- Mechanical operation, inherently explosion proof
- Unaffected by foam
- Simple to operate and maintain
- Operates on any liquid specific gravity
- Interface measurement
- Weatherproof case (standard for 25.4 cm dial only)

- Typical float designs are as follows:

Diameter		Height		Min. Liquid Density in gm/cm^3	Max. oper. pressure		Max. oper. temperature		Float Identification	Float Application
Inches	mm	inches	mm		PSIG	kg/cm^2	°C	°F		
Floats in Stainless Steel										
9-1/2	241	3	76	0.55	50	3.5	250	480	$\boxed{A}$	for standard use
5-1/2	146	5	127	0.85	150	10.5	250	480	B	for small branch entry
7-1/2	190			0.55	350	22.5	250	480	C	for medium pressures
8-1/2	216			0.45	250	17.5	250	480	C	same
10-1/2	266			0.28	120	8.5	250	480	C	same, and for low density liquids
Floats in Polypropylene, Polyethylene, PVC										
9-1/2	241	3	76	0.55	15	1.0	100	220	$\boxed{D}$	for standard use
7-1/2	190	2-1/2	64	1.1	300	21.0	100	220	E	solid-for high pressure applications
4-3/4	121	5-1/2	140	0.85	100	7	100	220	F	for small branch entry
3-1/2	89	7	178	1.1	100	7	100	220	F	same
Glass Float (Pyrex)										
5-3/4	146	7	178	0.68	45	3.2	250	480	G	For highly corrosive applications
Interface floats										
6	152	2-3/4	70	See	200	14.0	100	220	E*	for interface measurement with
7-1/2	190	2-1/2	64	note	300	21.0	100	220	E**	adjustable weights

Minimum difference in liquid density 0.2 gm/cm^3
* Stainless Steel ** Polypropylene, PVC, Polyethylene ☐Recommended float design



Standard floats are illustrated - special floats can be designed to suit more difficult applications.

- Materials of Construction include:

Guide Tubes and Mounting Flange -	Std.:	316 SS, Polypropylene, PVC
	Optional:	Teflon-covered SS
Floats -	Std.:	316 SS, Polypropylene, PVC
	Optional:	Glass, Monel
Cases -		Die-cast Alum. (with transmitter or switch) Rigid polyurethane cover & fiberglass housing (std.)

- Ranges:

  Dials - Any range from 0 to 2 ft (min.) to 0 to 36 ft (max.)

  Tapehead - Any range from 0 to 2 ft (min.) to 0 to 16 ft (max.)

- Scales:

Standard	Graduated in ft., in., or mm.
Special	Graduated in units of weight or volume of material

- Performance:

  Sensitivity -

  All units below 5.5m (18 ft) - float movement ±1.6 mm (1/16 in.)

  All units 5.5 to 10.9m (18 to 36 ft) - float movement ±3.2 mm (1/8 in.)

  Accuracy - ±0.5% of max. indicated depth

PRICES:

"Brooks-Mag" Flowheads	\$800-\$17,000
"Brooks-Mag" Signal Converters	\$600-\$12,000
"Maglink" Liquid Level Systems	\$200-\$1,200

COMMENTS:

Electromagnetic flowmeters were discussed generically in Section VI and no further comment will be made here. The "Maglink" liquid level system could find some application as a secondary device in conjunction with flumes and weirs, especially in difficult sites. All Brooks equipment outputs are computer-compatible either as standard design or available option.

MANUFACTURER: CONTROLOTRON CORPORATION
176 CONTROL AVENUE
FARMINGDALE, L.I., NEW YORK 11735
TELEPHONE (516) 249-4400

PRODUCT LINE: ULTRASONIC FLOWMETERS

DESCRIPTION:

Controlotron Corporation manufactures the Series 240 clamp-on ultrasonic flowmeter consisting of both a primary clamp-on unit and a secondary flow display computer and readout unit for use with pipe sizes from 2.54 to 152.4 cm (1 to 60 in.) in diameter. The acoustic technique employed is independent of liquid temperature, viscosity, turbulence, etc. The simple clamp-on installation requires no calibration or cutting of metal and can be performed by non-technical personnel. The Series 240 transducer consists of a transmitter and receiver unit positioned on opposite sides of the pipe. The transmitter, controlled by the flow display computer, injects an ultrasonic sound beam into the liquid through the pipe wall. The sound beam impinges on the receiver after passing through the liquid and the pipe wall adjacent to the receiver. If the liquid is flowing in the direction of the sound beam, the apparent speed of sound in the liquid is increased (or decreased if flowing opposite to the sound beam).

The pipe construction and the type liquid within determine whether or not the Series 240 ultrasonic flowmeter is suitable for a particular application. Controlotron will test 0.24ℓ (8 oz) samples of the liquid and samples of the pipe at no cost to the user to determine suitability. Applications for which clamp-on models are not recommended by Controlotron include pipes made of cast iron or any other material with an irregular exterior or on pipes with linings that would attenuate the acoustic signal. Insert transducers are used for this type of service. These are similar to the transducers that are used for open stream or channel measurement, and are made to order based upon the application specifications. Controlotron does not recommend use of ultrasonic velocity measurement devices in liquids that are high in undissolved solids or gases, e.g., slurries of sand-like particles, foams, or other aerated liquids, etc. Very rapid (less than 60 seconds) changes in liquid characteristics (that would change its sonic velocity) will result in temporary self-calibration failure and erroneous readings.

SPECIFICATIONS:

Flow Range:	0-9.1 m/s (0-30 fps)
Resolution:	0.0015 m/s (0.005 fps)

Accuracy:	From ±0.25% to ±2%, with ±1% of Full Scale Reading nominal. Larger sizes are more accurate, and Controlotron will quote expected accuracy for a given application.
Repeatibility:	±0.05%
Indication:	Standard 3-1/2 Digits
Outputs:	Digital - BCD Optional - Analog 0-10V, 4-20 mADC Totalizer - 6 Digits Alarm - Settable Hi and Lo Flow Alarms
Power:	115/230 VAC, 50-60 Hz, 75 watts

Dimensions:

Transducer - L = Pipe O.D. + 15.24 cm (6 in.) (Approx)
Flow Display - 25.4x33.0x38.1 cm (10x13x15 in.)
Counter - 20.3x30.4x35.6 cm (8x12x14 in.)

PRICE:	Starts at approximately $2,000 for a 25.4 cm (1 in.) pipe.

COMMENTS:

The equipment is factory calibrated either with water or the intended liquid, as appropriate. This is for fully developed flows with Reynolds numbers exceeding 10,000. It can be calibrated for any flow including laminar, and Controlotron reports that models with settable flow range factors and tracking of flow profile through the laminar flow region will soon be available. A zero offset adjustment may be required upon installation. Experience in metering raw sewage with this equipment is limited at this time and no definite statements about its suitability can be made. The manufacturer is expanding its product line and adding new features that may well increase the likelihood of their successful use as flowmeters for storm and combined sewer discharges (but not in the clamp-on configuration for most installations). An acoustic level gage that could be used with a number of primary devices such as weirs and flumes is also under development.

MANUFACTURER:	COX INSTRUMENT DIVISION OF LYNCH CORPORATION 15300 FULLERTON DETROIT, MICHIGAN 48227 TELEPHONE (313) 838-5780
PRODUCT LINE:	VARIABLE AREA FLOWMETERS; TURBINE FLOWMETERS; FLOW NOZZLES; FLOW INDICATORS

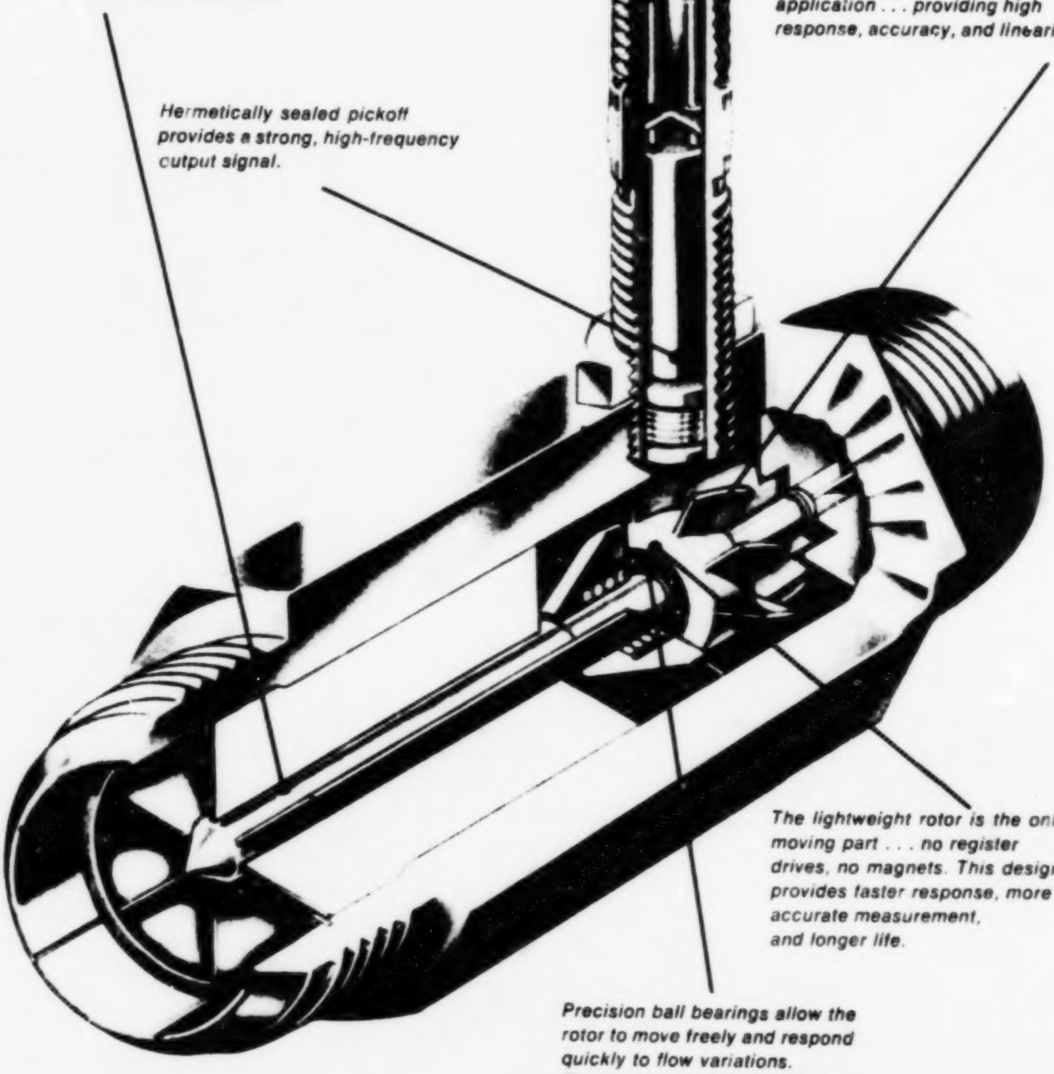
DESCRIPTION:

Primary Devices

Cox Instrument has long been recognized as a manufacturer of precision flow measuring equipment, especially as related to fuel, oil, gas, and industrial process fluid flows. The company proudly claims that "over 95% of the world's commercially-built liquid flowmeter calibrators now in use were designed and fabricated by Cox Instrument." This includes one presently being used by the National Bureau of Standards. Cox has also produced custom designs and systems for special applications.

The company offers a wide line of variable-area flowmeters. Such devices are not considered at all suitable for storm or combined sewer applications and, hence, will not be discussed. Cox also has a very wide line of turbine meters; capacities range from 0.00044 to 1770 ℓ/s (0.000016 to 62 cfs), with accuracies to 0.05% of reading available and response times better than 50 milliseconds. One of these typical turbine meters is shown in Figure A, which also indicates some of the distinguishing features of a Cox turbine. Turbine flowmeters are not considered suitable for most sewer flows and will not be discussed further.

Cox also makes a flowmeter called the VR-30 which, it is claimed, presents a new concept to the field of industrial flow measurement. It uses the principle of variable reluctance: a spring-loaded, force-balance spool is displaced in a magnetic field by the force of fluid flow. This changes the coupling in an external circuit. Because the spool is displaced in a contoured cross-section, the square root is extracted automatically, resulting in a linear output. The advantages to this approach are bi-directional output; unrestricted mounting position; in-line installation; and low maintenance operation. The VR-30 is said to handle corrosive, toxic, contaminated, or volatile fluids or slurries, at pressures to 3,000 psi and temperatures to 121°C (250°F). It is accurate to ±2% of full scale. Prices start at under $300, complete with remote indicator. The VR-30 may also be purchased with a more sophisticated readout device for analog and pulse output, providing for continuous process control or direct computer input.



Flow straightening design so precise that additional straightening is rarely necessary. Pressure loss is insignificant.

Configuration of rotor blades is designed to meet exactly the requirements of meter and its application . . . providing high response, accuracy, and linearity.

Hermetically sealed pickoff provides a strong, high-frequency output signal.

The lightweight rotor is the only moving part . . . no register drives, no magnets. This design provides faster response, more accurate measurement, and longer life.

Precision ball bearings allow the rotor to move freely and respond quickly to flow variations. Bearings are field replaceable . . . no need to return entire unit to factory. Different types of ball bearings are used to match the requirements of the meter. Special sleeve bearings of a variety of materials are also available for heavy-duty industrial applications.

Figure A

This device may have some wastewater applications, but is not considered well suited for most storm or combined sewer flow measurements. It will not be discussed further.

Cox manufactures twenty standard sizes of flow nozzles (Figure B) in two series with bore diameters ranging from 0.3 to 22.9 cm (0.128 to 9 in.). The standard approach to bore diameter ratio is 3:1, but the larger sizes are available on request in a 2:1 ratio. Cox nozzles are available either calibrated or uncalibrated. Nozzles are calibrated by using a positive displacement prover tank, a standard "Master" orifice, or both. Pressure differential across the nozzle is determined by using a micromanometer accurate to 0.005 cm (0.002 in.) of water. Standard calibration is to within ±1.0%. With calibrated nozzles, a curve of "Differential Pressure versus Flow Rate" (based on 14.7 psia and 70°F) is supplied with a copy of actual calibration data and correction factor determinations. Calibration at other than the standard condition noted can be obtained on special order. Flow nozzles were thoroughly discussed in Section VI and will not be commented on again here.

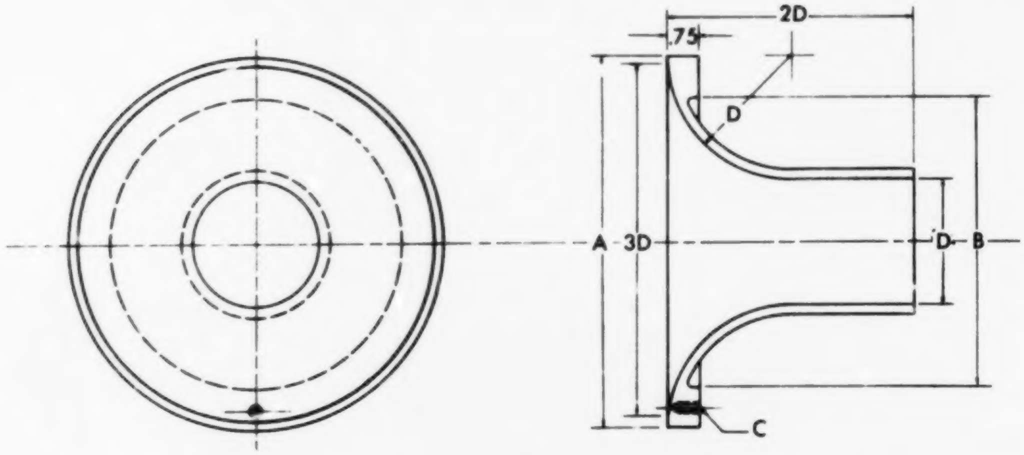


Figure B

Secondary Devices

In addition to turbine meter signal conditions and displays, Cox manufactures a number of basic electronic modules for signal conditioning, conversion, display, etc., that could be used as "building blocks" in assembling a custom system. One such unit will be described as an example, but such basic components lie outside the general scope of this writing.

Cox Variable Time Base P1B - Using integrated circuit (IC) techniques, the P1B module provides signal conditioning of low level AC signals for input to counters. The P1B may be used to increase the flexibility of almost any counter currently made. It is not limited to Cox-built equipment, and will interface with most major manufacturers' counters. In addition to signal amplification and conditioning, the P1B module provides gate, reset, and display control of ancillary counters. The variable time base (gate control) is a direct setting digital selector. A four digit time base selector permits selection of 0.000-10.000 seconds gating time in steps of 0.001 seconds. The time base affords an easy means of displaying the frequency output of a transducer in direct reading units (e.g., GPM, RPM). The P1B may be used with Cox P3A coun counter for the direct display of a frequency signal in engineering units. Turbine meters produce a frequency proportional to flow-rate. By preselecting appropriate gate time, the display is in GPM units.

Design features include:

- Advanced IC design employed.
- TTL (transistor-transistor logic) assures superior noise immunity.
- Designed for compatibility with pulse transducers present or future.
- Standard high sensitivity (3 mV) eliminates need for intermediate transducer amplification.
- Short circuit protection against both installation error and ancillary equipment failure.

MANUFACTURER: CUSHING ENGINEERING INC.
3364 COMMERCIAL AVENUE
NORTHBROOK, ILLINOIS 60062
TELEPHONE (312) 564-0500

PRODUCT LINE: ELECTROMAGNETIC WATER CURRENT METER

DESCRIPTION:

The Series 600 VELMETER, an electromagnetic water current device, is designed to measure flow velocity in oceans, streams, rivers, estuaries, aqueducts, sewers, etc. Operational features include no moving parts, zero threshold, fast response times, cosine response, special noise rejection circuitry, linear output, and anti-fouling coating.

The meter consists of a flow sensor connected to a signal converter by means of a cable and is offered in several configurations. These include an explosion-proof housing, NEMA 4 (weatherproof) housing, portable housing, rack-mounted panel, and kit form for the converter unit; 60-Hz or battery power; flange connection (with No-Foul protection) type sensor; or streamlined type sensor (for use when flow direction is known).

The VELMETER sensor produces a flow-generated voltage of approximately 20 MV per 0.3 m/s (1 fps) of flow velocity. The sensor's electromagnet requires a (rms) constant current drive, which is provided by the signal converter. The converter accepts the flow-generated voltage from the sensor, amplifies it, and conditions it to produce a final analog voltage output of ±5 volts for ± full scale flow. The converter also conditions the signal to provide optimal filtering of spurious wideband noise that is picked by the sensor (such as 60-Hz noises generated in waters near urban and industrial areas).

There are several sensors that can be used with this metering device. The Series 501 sensor incorporates one pair of detection electrodes and provides an output voltage proportional to the vector component of flow perpendicular to both the line connecting the two electrodes and to the axis of the sensor. The series 502 incorporates two pairs of detection electrodes and provides two output voltages, measuring two vector components of water flow. The series 81/82 sensors are, respectively, single-component and two-component devices which produce approximately six times the flow signal power of the Series 500 sensor; this sensor is said to perform within specifications for flow velocity up to 15.2 m/s (50 fps).

SPECIFICATIONS:

Range:	Full Scale, adjustable to 0.09, 0.30, 0.9, 3.0, or 9.14 m/s (0.3, 1, 3, 10, or 30 fps)
Output Time Constant:	Adjustable to 0.1, 0.3, 1, 3, or 10 seconds

Maximum Error Band:

	CONVERTER MODEL NO.		UNITS
	611/612	631/632	
Span or linearity	±1	±2	Percent of Full Scale
Zero Offset	±0.01	±0.05	Feet per second
Random Noise, rms*			
Series 500 sensor	$0.006/\sqrt{T}$	$0.030/\sqrt{T}$	Feet per second where T is the output time constant in seconds
Series 80 sensor	$0.002/\sqrt{T}$	$0.010/\sqrt{T}$	
Series 80 sensor with Magpower option	$0.001/\sqrt{T}$	$0.005/\sqrt{T}$	

* Apparent peak-to-peak noise on a recorder depends largely on chart speed; but approximately, apparent peak-to-peak noise is 6 times rms. value.

PRICE: $2,000 - $3,000 depending upon configuration.

COMMENTS:

This device should find some use as an attended survey unit in its portable configuration. Because of the obstruction to the flow offered by the standard probe configuration, some ingenuity would have to be exercised in mounting if damage from debris in the flow is to be avoided.

MANUFACTURER: DANIEL INDUSTRIES, INC.
P.O. BOX 19097
HOUSTON, TEXAS 77024
TELEPHONE (713) 467-6000

PRODUCT LINE:

PRIMARY DEVICES - ORIFICE PLATES AND METERS, TURBINE METERS, FLOW NOZZLES

SECONDARY DEVICES - DIFFERENTIAL PRESSURE TRANSDUCERS, TRANSMITTERS, AND CONVERTERS, INDICATORS, AND TOTALIZERS (CALLED FLOW COMPUTERS)

DESCRIPTION:

Primary Devices

Daniel Industries, Inc. manufactures a full line of orifice plates and flanges, orifice metering tubes, bored orifice flow sections, and orifice fittings for line sizes varying from 0.6 cm (1/4 in.) to 1.5m (4 ft) in diameter. Their "Senior" orifice fittings have a dual chamber design (Figure A) that permits the orifice plate to be removed from pressure lines safely and quickly; this facilitates regular inspection and maintenance. "Junior" orifice fittings and "Simplex" orifice plate holders are made for application where line by-pass or pressure shut-down is permitted. A large range of orifice flanges for use where it is not necessary to make regular plate inspections is also offered, as are orifice meter tubes and bored orifice flow sections for use where greater accuracy is required.

Daniel manufactures a "PT" line of liquid turbine meters (Figure B) in sizes from 1.3 cm (1/2 in.) to 61 cm (24 in.). These meters are intended for use where highly accurate measurement of large liquid volumes is required, e.g., custody transfer. Each meter can be fitted for bi-directional flow. Normal (linear) flow ranges are around 10:1 and extended flow ranges are from around 15:1 to 40:1, depending upon size.

Daniel also manufactures a full line of precision flow nozzles (ASME long radius and ASME throat top) including flanged, weld-in, and holding ring types in a wide variety of materials (Figure C). For highest metering accuracy, a fully assembled flow nozzle and meter tube is offered. Large volume custom meter stations and proving systems are supplied in virtually any size and capacity.

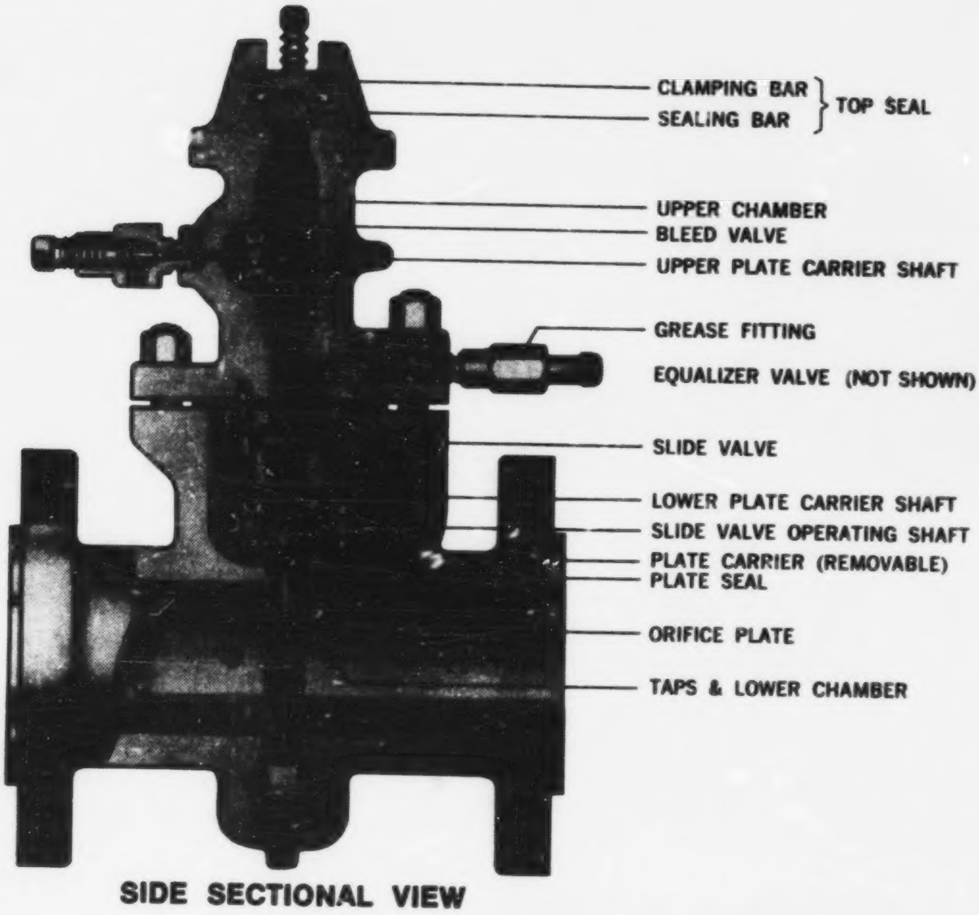

CLAMPING BAR
SEALING BAR
TOP SEAL
UPPER CHAMBER
BLEED VALVE
UPPER PLATE CARRIER SHAFT
GREASE FITTING
EQUALIZER VALVE (NOT SHOWN)
SLIDE VALVE
LOWER PLATE CARRIER SHAFT
SLIDE VALVE OPERATING SHAFT
PLATE CARRIER (REMOVABLE)
PLATE SEAL
ORIFICE PLATE
TAPS & LOWER CHAMBER
SIDE SECTIONAL VIEW

Figure A

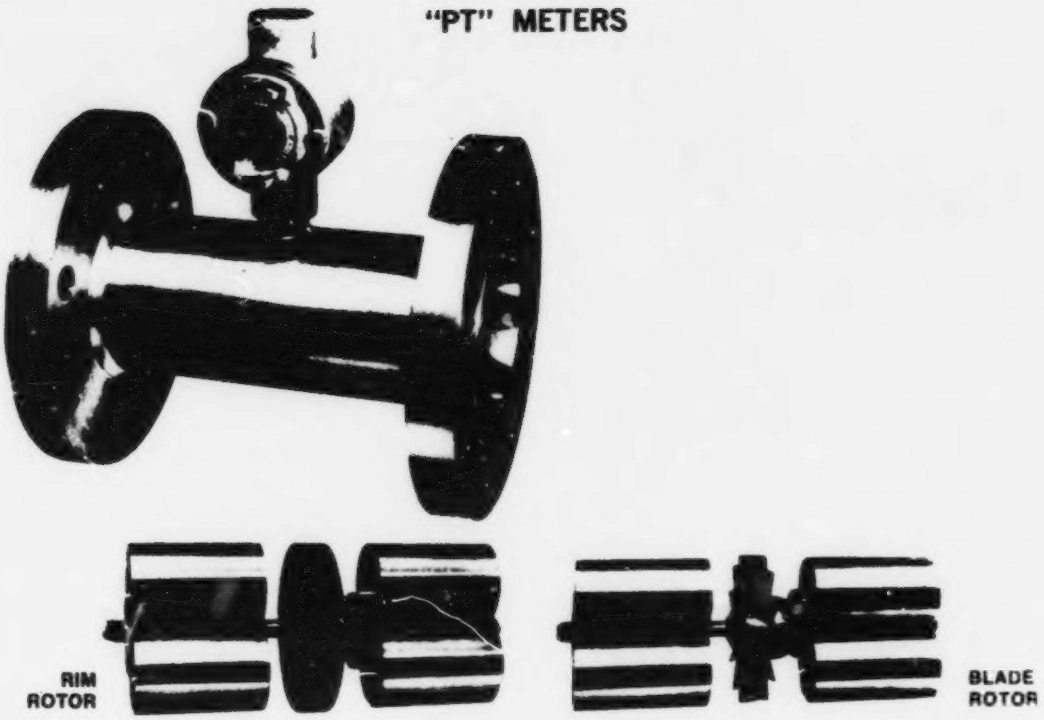
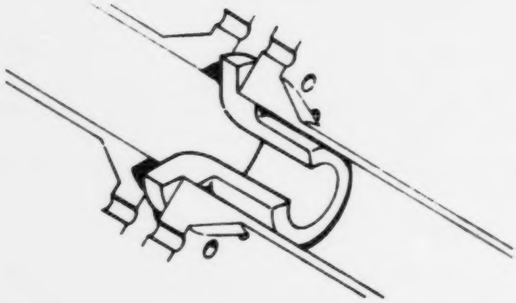
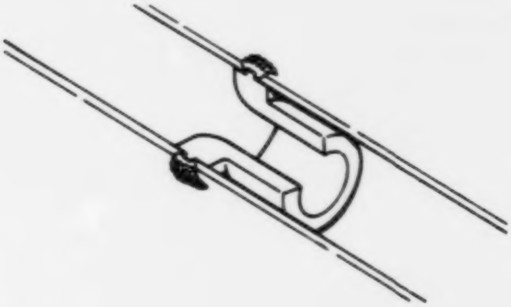

"PT" METERS
RIM ROTOR
BLADE ROTOR

Figure B

FLANGED FLOW NOZZLE

This type of nozzle has a flange on its upstream end which is installed between pipe flanges to hold the nozzle concentric with the inside of the pipe. The nozzle flange can be furnished in any series of facing (raised, ring-joint, etc.) specified.





WELD-IN FLOW NOZZLE

This nozzle has a machined tongue around its greatest diameter which fits between beveled ends of both an inlet and outlet pipe section. The sections, with the nozzle in place, are firmly clamped and/or tack-welded together in perfect alignment before the finish weld is applied.

HOLDING RING FLOW NOZZLE

This nozzle is another welding type for installation in pipe without flanges. The nozzle is installed in a section of carefully selected and internally bored pipe with the curved nozzle inlet facing upstream.

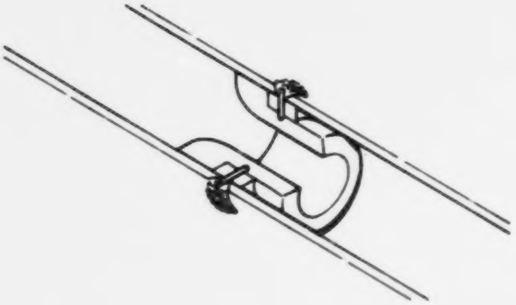


Figure C

Secondary Devices

Daniel supplies a wide range of differential pressure transducers, transmitters, counters, and indicators and totalizers (called flow computers) for use with all of its primary elements. A typical differential pressure flow computer might take a 4-20 mADC signal that is proportional to pressure difference and convert this into: a visual indication of flow rate on a front panel meter; a 4-20 mADC electrical output that is proportional to flow rate; a visual, six-digit indication of totalized flow; and an electrical dry contact closure per each totalizer advance. Flow rate recordings are not normally supplied, but could be on special order. Similar outputs are available from secondary elements for use with turbine meters.

COMMENTS:

Much of the Daniel product line was developed for the oil and gas industry and is more typically suited for this application than for measuring storm and combined sewer flows. There might be some uses for their flow nozzles and orifice meters in measuring sewage flow, but the turbine meter is not at all suitable. For this reason no detailed specifications or prices will be given.

MANUFACTURER: DREXELBROOK ENGINEERING COMPANY
205 KEITH VALLEY ROAD
HORSHAM, PENNSYLVANIA 19044
TELEPHONE (215) 674-1234

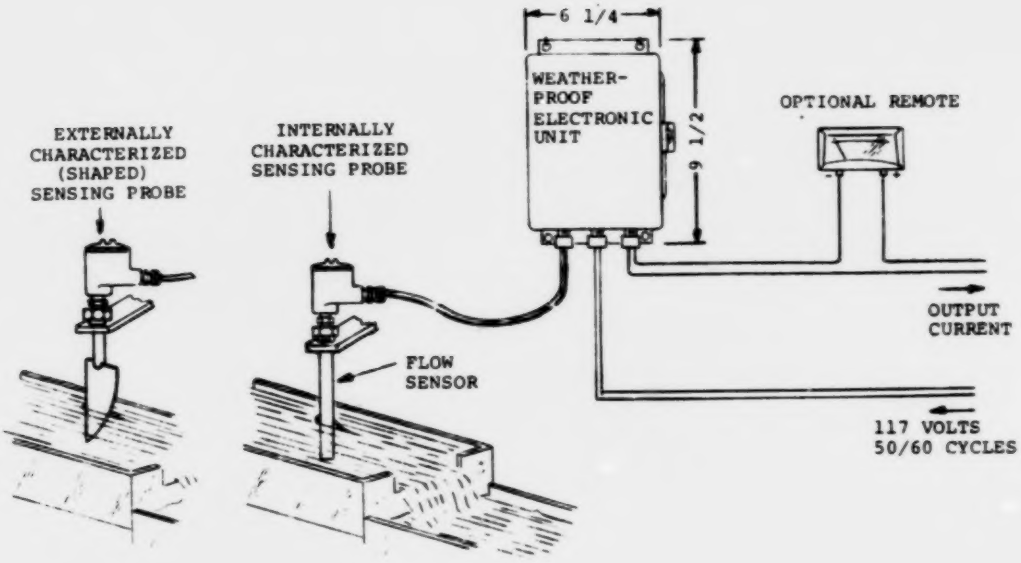
PRODUCT LINE: LEVEL GAGES

DESCRIPTION:

Drexelbrook manufactures a wide line of secondary flow measuring and indicating systems in their Series 508 (see Figure A). The Drexelbrook "Cote Shield" flowmeters provide reliable and accurate measurement of the flow of clean or dirty liquids through virtually any head-area primary device such as flumes, weirs, etc. The flowmeters contain no moving parts, floats, or air purge tubes; they cannot plug, and are unaffected by coating of solids such as slush, mud, algae or slime, build-up, paper, sludge, etc. The sensing element is static and can be installed either directly in the moving stream or in a stilling well.

The sensing element is basically a precision admittance-to-current transducer. It will provide an output current directly proportional to the input admittance presented by the sensing element. Each measured flow rate corresponds to a specific level in the weir or other primary device. This variation in level will cause minute amounts of current to flow from the sensing probe to the grounded stream. A compensated bridge circuit is used to accurately measure the change in current. The output of the bridge circuit is a DC voltage which is a measure of the true flow rate. The output voltage is amplified in a feedback amplifier to provide an output current directly proportional to flow and unaffected by the output resistance. The output current can be used to operate a variety of accessories such as remote meters, recorders, alarm circuits, and electro-pneumatic transducers.

Drexelbrook has a number of the Series 508 models available both with and without "cote-shield" action for clean or dirty liquids that vary in calibrated immersion depth of the sensor probe from 30.5 to 91.5 cm (12 to 36 in.). Standard systems are available for use with any 3/2- or 5/2-power low head-area device (most commonly used with weirs and flumes). Linear systems (e.g., for use with a sutro weir or Kennison nozzle) are routinely made to order, and virtually any depth-discharge characterization can be provided on special request. Both internally and externally (shaped) characterized probes are available. For direct, in-stream applications where damage due to large debris (floating logs, rocks, etc.) is a possibility, Drexelbrook offers an optional tilt-away mounting in which the probe is held in the flow by an adjustable counterweight but is free to pivot up out of the way when struck by an object in the flow. This mounting is also recommended when extreme build-up


6 1/4
WEATHER-PROOF ELECTRONIC UNIT
9 1/2
OPTIONAL REMOTE
EXTERNALLY CHARACTERIZED (SHAPED) SENSING PROBE
INTERNALLY CHARACTERIZED SENSING PROBE
FLOW SENSOR
OUTPUT CURRENT
117 VOLTS 50/60 CYCLES

SERIES 508 FLOWMETER

Figure A

of fibrous materials such as rags and paper are expected. As large build-ups occur, the increased drag on the probe will cause it to tilt up and allow the fibrous materials to wash away.

Optional integrators (totalizers), batch counters, remote readouts, etc., are available as are such extras as lighted meter case, explosion - proof housings, special mountings including extra-long probes, etc.

SPECIFICATIONS;

Accuracy:	Direct function of primary device. Flowmeter output is linear within ±0.5%.
Standard Output Current Ranges:	4-20 mA thru 0 to 1500 ohms 1-5 mA thru 0 to 6000 ohms 10-50 mA thru 0 to 600 ohms
Load Resistance Effect:	0.1% from 0 to maximum resistance
Power:	95 to 145V, 50/60 Hz with a ±0.5% effect on accuracy for input voltage changes ranging from 95 to 135 VAC. DC operation optional.

PRICES:

Basic Series 508 Systems range from $553.00 to $1,371.00

COMMENTS:

These devices appear very well suited for use with various primary devices to measure storm and combined sewer flows at many sites. They are essentially factory calibrated, and only a few field adjustments are necessary. It should be noted that the entire calibrated length of the sensor is not available for accurate measurement of flow. For example, for 3/2 power law probes, the liquid level should always lie between 1/3 and 3/3 of the calibrated length. Thus, a 51-cm (20-in.) maximum calibrated length sensor should not be used for heads greater than 51 cm (20 in.) nor less than 15 cm (6 in.). An additional interesting feature is that, based upon an application description, Drexelbrook will quote on a guaranteed performance basis. If the equipment does not perform within the quoted specifications, it may be returned for free repair, replacement, or credit.

MANUFACTURER: EASTECH INCORPORATED
2381 SOUTH CLINTON AVE.
SOUTH PLAINFIELD, NEW JERSEY 07080
TELEPHONE: (201) 561-1000

PRODUCT LINE: EDDY-SHEDDING PRIMARY DEVICES; TRANSMITTERS, FLOW CONVERTERS, INDICATORS, TOTALIZERS

DESCRIPTION:

Eastech Incorporated makes the VS-21 series vortex shedding element for the measurement of flows of gases, liquids, and slurries. Also offered is a selection of secondary instrumentation including transmitters for various applications, several flow converters, a digital rate indicator, and a totalizer.

Flowmeters

The VS-21 digital flowmeter (patented under the trade name of VS-21 Flow Transmitter) is the primary flow measuring device, and forms an integral part of various flow transmitters in the manufacturer's product line - both "full pipe flow" type and insertion flow variety. In conjunction with the transmitter and sensor elements, this device utilizes the principle (or effect) of vortex eddy-shedding to measure the flow velocity. The VS-21 generates pulse signals over very wide flow ranges (up to 200:1) at a frequency proportional to the flow rate. It currently utilizes any one of four sensing techniques to measure flow. Three of these techniques employ thermistors; the other makes use of a "shuttle-ball" concept, in which a "captive" hollow nickel ball is driven by the effect of vortex shedding.

In the thermistor techniques, an electrical current is passed through the thermistor, heating it and making it responsive to the cooling effects of flow. The changes in flow velocity across the thermistor due to vortex shedding result in changes in its temperature, thus resulting in corresponding changes in its resistence. In the front face thermistor technique (Figure A), two coated thermistors are bonded into the front face of the flow element and operated differentially.

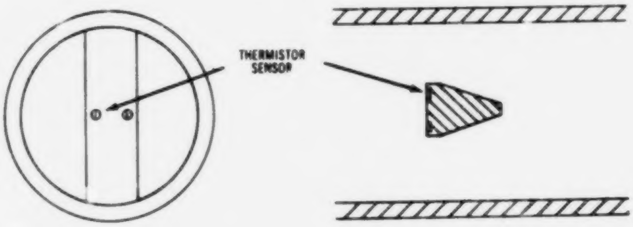


Figure A

The vortex shedding behind the flow element affects the direction of flow impinging on the front face, causing out-of-phase velocity variations at the two thermistors. This is the approach used by Eastech for wastewater and slurry flow measurement applications.

The "central" thermistor technique (Figure B) utilizes a passage drilled through the flow element. The generation of the vortices alternately on either side of the passage causes flow to move back and forth in the passage and across a single, removable thermistor sensor assembly which is mounted through one end of the flow element.

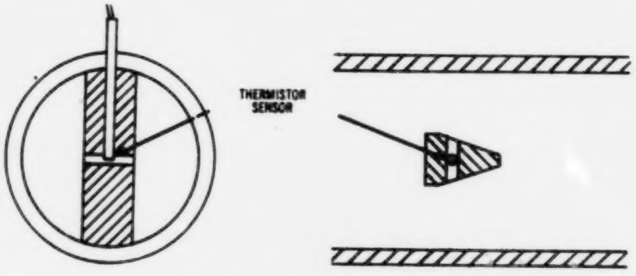


Figure B

The external thermistor technique is similar to that of the central sensor except that it is located in a passage external to the meter. Figure C shows this arrangement.

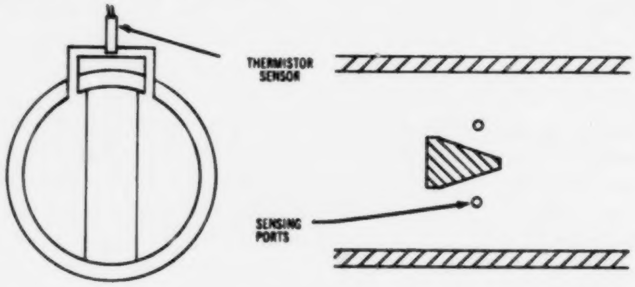


Figure C

The shuttle-ball method (Figure D) employs vortex shedding to drive a hollow nickel ball back and forth along the axis of the flow element. The motion of the ball is detected by a magnetic pickup. The calibration factor of the meter depends only on the dimensions of the flow element and the pipeline.

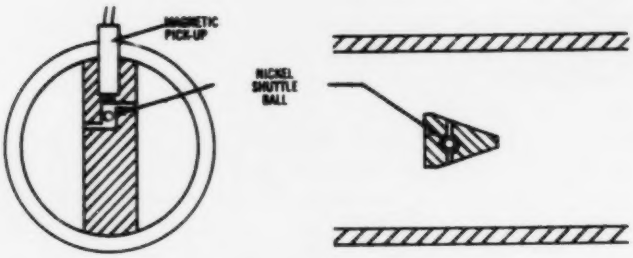


Figure D

Flow Transmitters

As indicated by Eastech, the transmitter models discussed below are the ones recommended for wastewater and slurry applications.

The Model 2210 and 2220 flow transmitters have flanged, spool style bodies and removable VS-21 flow elements. These devices feature two front face thermistor sensors and an explosion-proof, close-coupled solid-state amplifier. This amplifier (also incorporated in the Model 2500/2600 series) is provided to increase signal amplitude prior to its transmission to a flow converter which may be remotely located up to 762m (2500 ft) away. As noted previously, the VS-21 generates output pulse signals at frequencies linear with volumetric flow rate over ranges up to 100:1 (200:1 optional). Basic line sizes are from 3.8 to 15.2 cm (1.5 to 6 in.). Other sizes are optional.

The Model 2510 flow transmitter also employs the front face thermistor technique (Figure A) and has two wet-tap thermistors that can be removed for inspection without interfering with the flow through the device. The thermistors are mounted on removable shafts flush with the face of the flow element. The transmitter may be connected with flow converter instrumentation at distances up to 762m (2500 ft). This model, especially recommended for use on slurries and liquids containing significant amounts of clogging solids, is offered in line sizes ranging from 20.3 to 91.4 cm (8 to 36 in.).

Models 2610, 2620, and 2630 are called "insertion flow" transmitters but are actually velocity probes. These devices have a shrouded flow element with front face thermistor sensors (see Figure A) mounted on the end of a shaft passing through a sealed mounting flange. The fixed model 2610* (Figure E) is used where the line pressure can be relieved for installing or removing the flow transmitter from the line. As stated by the manufacturer, the insertion depth cannot be altered without removing the device from the pipeline, making it in a sense "tamper-proof". The adjustable, hot tap model 2620 (Figure E) can be removed or installed (manually against pressures up to 60 psig) through a block valve without interference with process flow. The model 2630 has a threaded shaft enabling it to be inserted into a high-pressure liquid stream without "blowing down" the pipeline or interrupting flow. Both models 2620 and 2630 are recommended for situations where costs may prevent the use of full pipeline meters, or where it is necessary to remove the metering device for inspection or pipeline "pigging". These transmitters may also be used to traverse across a pipeline to determine velocity profile and are suitable for use in effluent monitoring systems. As with the full pipe flow transmitters, these models can be used with flow converters located up to 762m (2500 ft) away from the site. These transmitters are usable in pipelines ranging from 20.3 to 274 cm (8 to 108 in.).

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* Also offered is the adjustable model 2640. It is similar to the 2610 except insertion depth can be adjusted with the flow transmitter installed.

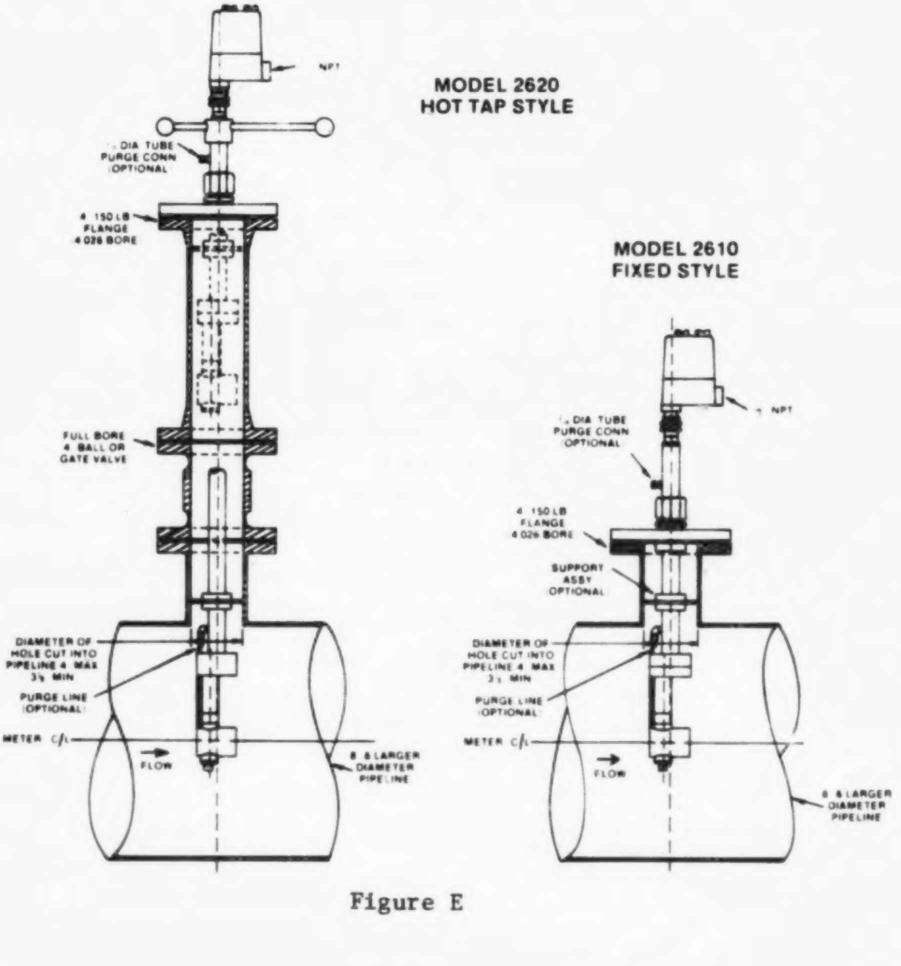

MODEL 2620
HOT TAP STYLE
NPT
DIA TUBE PURGE CONN (OPTIONAL)
4 150 LB FLANGE 4 026 BORE
FULL BORE 4 BALL OR GATE VALVE
DIAMETER OF HOLE CUT INTO PIPELINE 4 MAX 3½ MIN
PURGE LINE (OPTIONAL)
METER C/L
FLOW
8 & LARGER DIAMETER PIPELINE
MODEL 2610
FIXED STYLE
NPT
DIA TUBE PURGE CONN (OPTIONAL)
4 150 LB FLANGE 4 026 BORE
SUPPORT ASSY OPTIONAL
DIAMETER OF HOLE CUT INTO PIPELINE 4 MAX 3½ MIN
PURGE LINE (OPTIONAL)
METER C/L
FLOW
8 & LARGER DIAMETER PIPELINE

Figure E

Flow Converters/Indicators

Eastech offers several flow converters for use with the VS-21 flowmeter. These include Models 4100 and 4200 and the Model 44 digital flow rate indicator. The 4100 is designed for stationary or over-the-road applications, accepts signals from a VS-21 flow transmitter, and provides a conditioned pulse output. Optional features include scaling to engineering units, totalizers, and analog rate indicators.

Model 4200 is similar to the 4100 except that it provides field adjustable scaling to engineering units and can be panel mounted.

The Model 4400 displays flow rate in digital form. It has a small plug-in module which permits direct reading in any desired engineering units.

SPECIFICATIONS:

Model 2210 and 2510 Transmitters

Repeatability:	±0.1% of reading, or better
Linearity:	±0.5% of reading (at pipe Reynolds numbers of 10,000 and above)
Calibration Accuracy:	±0.25%
Pressure Loss:	0.4 atm at m/s (20 fps)
Response Time:	1 msec @ 500-Hz signal frequency
Minimum Measurable Flow:	Corresponding to pipe Reynolds number of 5,000
Flow Capacity:	2.54 cm (1 in.)* - 302.8 ℓ/s (80 gpm) 91.44 cm (36 in.)* - 340,650 ℓ/s (90,000 gpm)
Turn-Down Ratio:	10:1 & 100:1 (standard); up to 200:1 (optional)

Model 2600 Series Transmitters

Repeatability	±0.1% of reading or better
Linearity:	±2% of reading (at Reynolds numbers 10,000 and above based on flow element dimension of 5.1 or 10.2 cm (2 or 4 in.)

---

* Meter Size

Calibration Accuracy:	±1%
Pressure Loss:	Negligible
Response Time:	Same as Models 2200/2500 series
Minimum Measurable Flow:	Same as Models 2200/2500 series
Turn-Down Ratio:	Same as Models 2200/2500 series
Element Size	5.1 and 10.2 cm (2 and - 4 in.) diameter

PRICES:

Standard prices not available at the time of this writing.

COMMENTS:

There is necessarily an obstruction to the flow with all of these devices, so their use does not seem appropriate where large trash and debris are present in the flow. A well-conditioned flow is necessary for accurate readings, and a minimum of 20 to 40 pipe diameters in length of straight pipe (15 to 20 diameters if straightening vanes are used) is required upstream of the meter and at least two pipe diameters of straight pipe downstream. Gaskets upstream and near the meter must not protrude into the flow.

MANUFACTURER: EDO CORPORATION
13-10 111TH STREET
COLLEGE POINT, NEW YORK 11356
TELEPHONE: (212) 445-6000

PRODUCT LINE: ACOUSTIC-DOPPLER FLOWMETERS; PROBES, RECORDERS

DESCRIPTION:

The EDO sonic flowmeter operates on the doppler shift principle and is a further development of EDO's line of doppler current meters. The basic parts of the flowmeter (acoustic probe and receiver indicator) are depicted in Figure A.

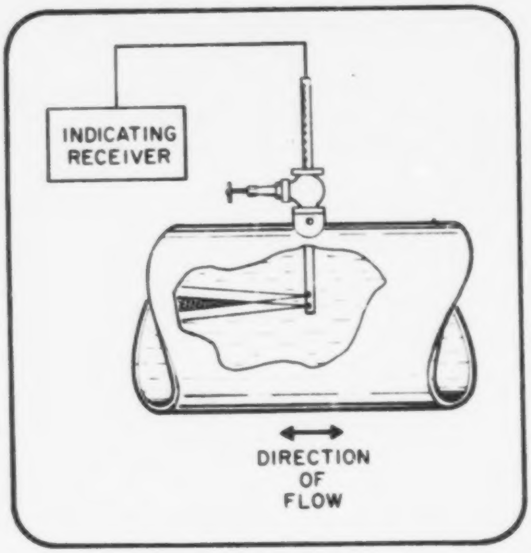


Figure A

An acoustic probe, containing two transducers, is positioned in the flow. It is normally oriented to point upstream, although the probe is actually bi-directional. One transducer projects an acoustic signal, which is reflected by waterborne particles and disturbances. The reflected signal, frequency shifted proportionally to the velocity of the fluid, is received by the other transducer. An electrical signal proportional to fluid velocity is converted to flow rate by means of processing circuits contained in the indicating receiver. The actual point of intersection of the two beams is one foot upstream from the probe, so that measurements are made in an undisturbed region of the flow field. Because the processing circuits are not sensitive to amplitude variations, the flowmeter is immune to changes in impurity concentration and peripheral noise.

Significant claims have been made for this device with respect to its use in wastewater applications. These are:

- The probe does not clog due to sediment or silt as, for example, the pressure ports of various flowtubes;
- The probe does not accumulate undue grease on the sensors, since they are located in a high-velocity region of the flow;
- The probe can be easily wiped free of grease, rags, and other materials because of its cylindrical shape.

In addition to its applications to flow measurements in pipes, the EDO flowmeter can be used for open-channel velocity measurements. The flowmeter has been used in fresh water, salt water, raw sewage and sludge.

EDO provides flowmeters and accessory equipment for both portable use and fixed installation. The model 763F is designed for fixed applications and model 763P is offered for portable uses.

Model 763F - The fixed flowmeter, with its automatic cleaning assembly, is installed at a specific point in the flow system. The cost of an EDO fixed flowmeter installation is essentially constant, regardless of the pipe-diameter, whereas the cost of magmeters, venturis, and similar in-line meters tends to increase dramatically with pipe diameter. Due to its ease of installation, the meter is particularly suited to retrofit applications. If user requirements dictate, it can be used in the interim period while an in-line meter is being repaired. Fixed flowmeter configurations can be altered to meet specific plant requirements. For example, receivers for two or more probes can be packaged in a single receiver unit, and local indicators or totalizers may be installed on the receiver panel.

An automatic wiping mechanism cleans the probe periodically by withdrawing and reinserting it through wiping glands. The period between cleaning cycles is controllable and is set according to existing conditions. The cleaning can be remotely actuated from a control panel, if chart-recorded flow readings indicate the necessity.

The mechanism provides unattended operation and requires only routine preventive maintenance every 6 months. No purging is required.

Model 763P - The portable flowmeter is general plant instrumentation, inserted and removed as required, for plant flow surveys, troubleshooting, evaluation of equipment, etc. Installation and insertion can be made without interruption of flow. Except for physical dimensions and weight, differences in the respective receiver/indicator configurations, and the fact that it is not equipped with automatic wiping mechanism, the portable flowmeter operates essentially the same as the fixed unit.

SPECIFICATIONS:

Instrumentation	
Flow Range	0.03 - 4.57 m/s (0.1-15 fps)
Pipe Size	15.24 - 243.84m (6-96 in.) dia
Accuracy	±1.5%
Acoustic Probe	
Frequency	3.0 MHz ± .005%
Power Output	1.3 watts
Transducer Spacing	1.9 cm (0.75 in.)
Transducer Angle	20°
Length of Cable Probe	up to 152m (500 ft)
Size of Probes	
Small	1.9x91.4 cm (3/4x36 in.)
Large	5.1x182.8 cm (2x72 in.) 3.048m (120 in.) (with probe extended)

PRICE:

Model 763F (Probe, Wiper Assembly, Receiver, Chart Recorder, Totalizer)

With Small Probe ------------------------------------	$ 9,345
With Large Probe------------------------------------	$10,300

Model 763P (Indicating Receiver, one Large or Small Probe, Cables)---	$ 2,930

COMMENTS:

These devices are essentially velocity probes and, hence, knowledge of flow velocity profiles is necessary in order to obtain flow discharge. They would appear suitable for open channel as well as full pipe flow given certain constraints. The sensing probe necessarily presents an obstacle to the flow and, in flows containing large trash or debris, it might be physically damaged. Hence, its use would seem inappropriate in this case. Otherwise, the self-cleaning feature would appear to be attractive and could allow its use in troublesome flows. These units are fairly new on the market, and wastewater application data are scant.

MANUFACTURER: ENVIRONMENTAL MEASUREMENT SYSTEMS
A DIVISION OF WESMAR
905 DEXTER AVENUE NORTH
SEATTLE, WASHINGTON 98109
TELEPHONE (206) 285-1621

PRODUCT LINE: ULTRASONIC FLOW MONITOR

DESCRIPTION:

Environmental Measurement Systems, a division of WESMAR (Western Marine Electronics, Inc.), is now in production with their Ultrasonic Flow Monitor, UFM-200, a completely packaged secondary device that "ultrasonically" measures and records continuous liquid flow. The UFM-200 (Figure A) is calibrated, prior to shipment, to the customer's flume or weir. There is no contact with material being measured (i.e., transducer is mounted over the weir or flume), since the system operates on the "sonar-in-air" (echo-sounding) principle. The sonar beam gives a constant transmission of the distance from the top level of the flow. This interval is converted to a voltage which is converted to flow rate and recorded, totalized, and displayed. The UFM-200 is a complete system with electronics, total flow counter, water sample rate counter (adjustable), recorder (strip chart), timer (duty cycle), and visual linear readout meter.

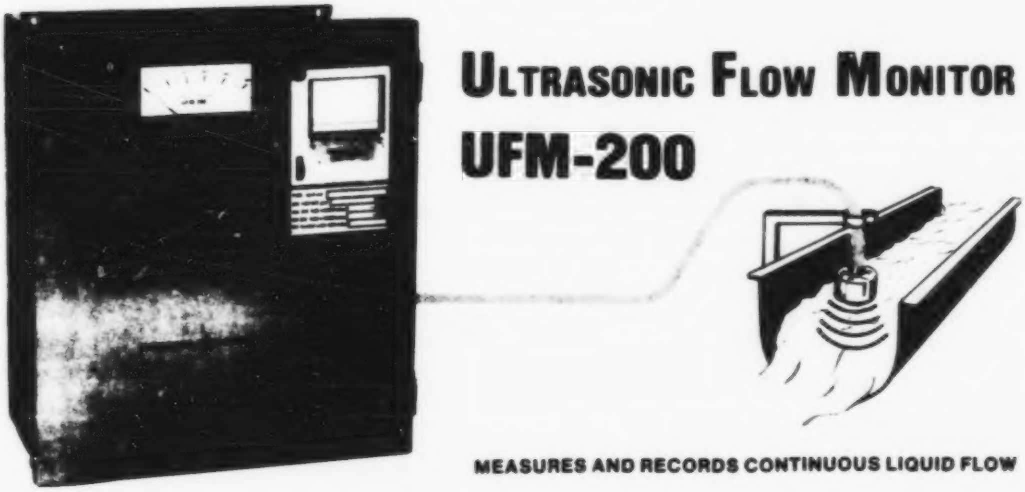


Figure A

The system has built-in circuitry that allows remote or portable installation through battery-powered operation. The total flow counter continuously displays the total amount of flow, in six digits, up to 1 billion gallons (3,785 billion liters); the permanent recorder records the converted and calibrated flow output in gallons per minute on a 6.35-cm (2.5-in.) inkless strip chart at a speed of 2.5 cm (1 in.) per hour.

SPECIFICATIONS:

Range:	3m (10 ft) (maximum) 41 cm (16 in.) (minimum)
Resolution:	within 1%
Repeatability:	within 1%
Linearity:	within 1%
Output Signals:	0 to 5 VDC (proportional to head) 0 to 5 VDC or 0 - 1 MADC (proportional to flow)
Pulse Proportional to Flow:	1 pulse every 1,000 gallons
Sensor Beam Pattern:	7° conical included angle
Remote Operation (Electronics to Sensor Separation):	Up to 91.4m (300 ft)
Input Power:	110/220 VAC, 50 to 60 Hz, 10 watts (or ±12 VDC)
Dimensions	
Enclosure: (JIC)	36x31x15 cm (14x12x6 in.)
Weight:	
Electronics:	15 kg (3 lb)
Sensor:	1 Kg (2 lb)

PRICE:

Not available at time of writing.

COMMENTS:

Some users have encountered difficulty due to echos (false signal returns) when using these devices in manholes. Putting a plastic shield around the transducer seems to solve the problem.

MANUFACTURER: EPIC INC.
150 NASSAU STREET
SUITE 1430
NEW YORK, NEW YORK 10038
TELEPHONE: (212) 349-2470

PRODUCT LINE: CURRENT METERS, COUNTERS/INDICATORS, STAGE MEASUREMENT DEVICES

DESCRIPTION:

Epic Inc. is the U.S.-based outlet for precision instruments and machinery manufactured by the West German firm of A. Ott Kempten. Epic and Ott offer a line of current (velocity) meters and a varied selection of secondary flow measurement devices, including counters, recorders, and indicators and several stage measurement devices (e.g., water level recorders, point gage, and a "flowmeter"). Most of these devices are designed primarily for measurement of water flows, but several have found application in the wastewater field.

Current (Velocity) Meters - Typical current meters in the Epic/Ott line include the Universal types 10.002 (C31), 10.200, and 10.300. Types 10.002 and 10.200 are similar in that they both produce signals generated by an impulse device actuated by a permanent magnet so that the rotation of the propeller is not slowed down by a contact system; the signals are totalized by an electromagnetic counter connected by cable to a magnetic switch, mounted in the meter body. It has been reported that the Type 10.002 (C31), shown in Figure A, has been used successfully (in conjunction with a specially-designed flow tube) by at least one large municipal government in the measurement of effluent flows. Types 10.002 (C31) and 10.200 are portable, battery-powered devices.

Type 10.300 is a permanent hydrometric flow measurement device. Unlike the 10.002 and 10.200, this instrument permits a direct determination of flow velocity and can be permanently installed. As do the other two current meters, the 10.300 produces a signal voltage that is proportional to water speed; this voltage can be read from an indicator in m/s. Telemetry of the measurements is possible.

The type propeller used, and its diameter and pitch, is determined by maximum flow velocity of the fluid into which it is placed. As shown in the following table, there is a variety of propellers for several applications -- including oblique flows as well as straight flows.

A variety of methods for indicating and recording flow velocities is available: direct indication via a servo system (for precision remote indication); four-digit digital readouts by a converter and readout

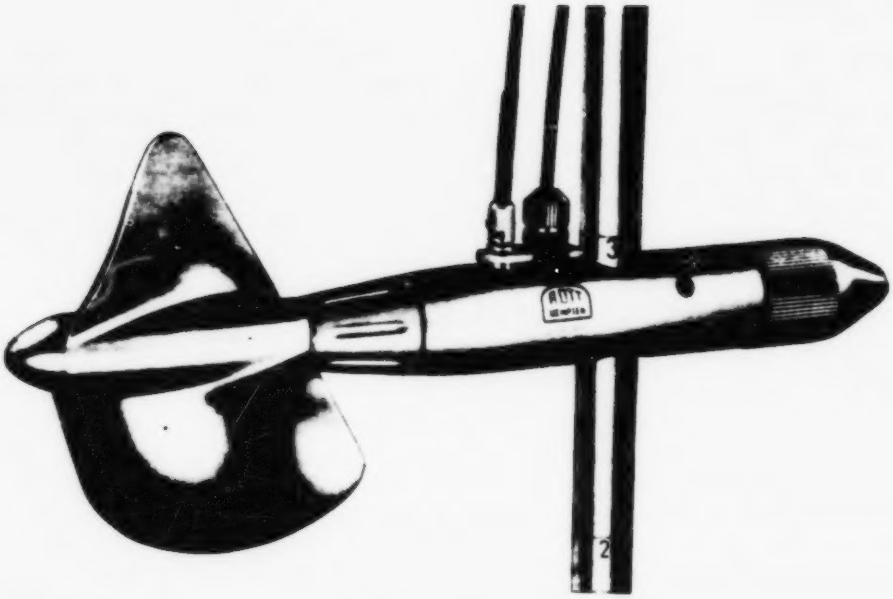


Figure A

Propeller		Propeller diameter		Propeller pitch		Max. flow velocity of water		Starting speed m/sec
Ref. No. for ordering	Type No. engraved	mm	in	m	in.	m/sec	ft./sec	
10.001.030.4.4	4	80	3 5/32	0.125	4 59/64	1.25	4.1	0.04
10.001.027.4.4	1	125	4 59/64	0.250	9 54/64	2.50	8.2	0.03
10.001.028.4.4	2	125	4 59/64	0.500	19 11/16	5.00	16.4	0.04
10.001.029.4.4	3	125	4 59/64	1.000	39 3/8	10.00	32.8	0.05
10.001.031.4.2 Component propeller up to 45° oblique flow	**A**	100	3 121/128	0.120	4 29/40	2.50	8.2	0.04
10.001.032.4.4 Component propeller up to 15° oblique flow	**R**	100	3 121/128	0.240	9 9/20	5.00	16.4	0.05

device; continuous recording of flow velocity on a compensating recorder (especially suitable for permanently installed velocity meters); and recording of the measured value by a portable, battery-powered mini-recorder (basically used with non-permanent meter installations).

Flowmeters - Epic offers the Type 22.001 "flowmeter" for indicating, recording, and counting the discharge at measuring weirs or open channels and in unpressurized pipe lines. A venturi flume can be provided with this unit. A water level-recorder with an electrical output (0-10 volts) is used as the measuring transmitter for the water level. Various systems of level meters can be employed -- e.g., pressure level gage, tube level gage, pressure level gage with transmitter-amplifier, float-type level gage, etc. Figures B through F show some typical applications of this meter. The Model 22.001 combines a direct reading indicator, counter, and strip recorder within a single cabinet.

1. Metering with the pressure level gage

A pressure transmitter is fastened on the bottom of the measuring channel. The device operates as an inductive measuring value sender. The mechanical part of the measuring value sender is a metal membrane. The deformation of the metal membrane resulting from the pressure of the water column standing over the sender is a function of the water height H. This deformation which lies for the nominal range in the magnitude of less than 0.2 mm is measured with an inductive measuring transformer and, over corresponding electronics, converted into a voltage of 5 volts for the nominal range.

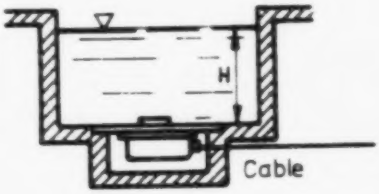


Figure B

2. Tube level gage (I)

In very muddy channels it is occasionally necessary, to clean the pressure level gage. In this case, the tube level gage is especially suitable. Here the inductive pressure transmitter is in the lower part of a tube. The sender is designed in such a way as not to touch the liquid of the measuring channel. For cleaning, the tube level gage is simply taken out of the liquid. The measuring amplifier can be fixed directly at the tube in order to have available at the measuring point a voltage for the level value of 0-10 volts. This tube level gage design offers the advantage that the installation can be made in the specific measuring channel without constructional modifications.

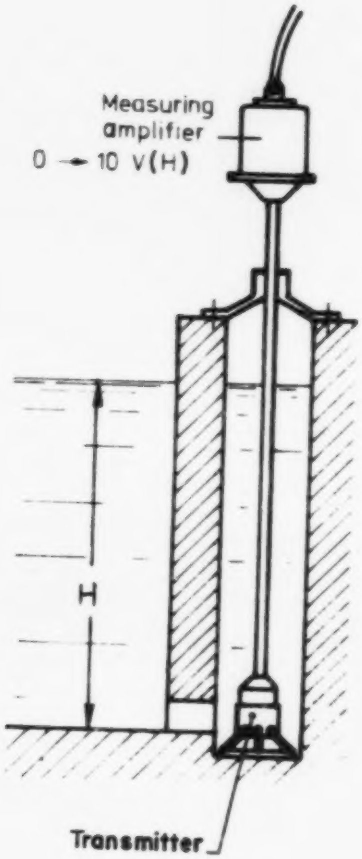


Figure C

3. Tube level gage (II)

In this configuration, the pressure transmitter is mounted to a metal foot which is anchored in the bottom of the measuring channel. In this way the transmitter is always flowed around by the liquid, thus avoiding the risk of getting polluted by deposition of mud, etc. This level meter is likewise mounted on a tube, which is arranged in the side wall of the channel. (By bedding the tube into the side wall, any disturbing effect to the flow conditions in the channel will be excluded.)

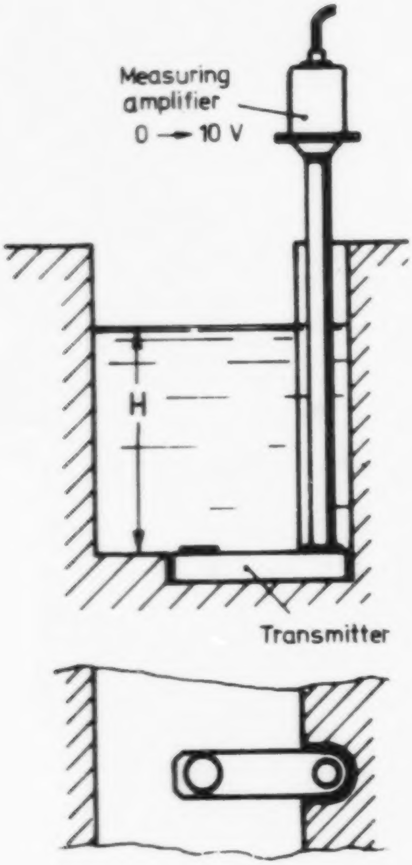
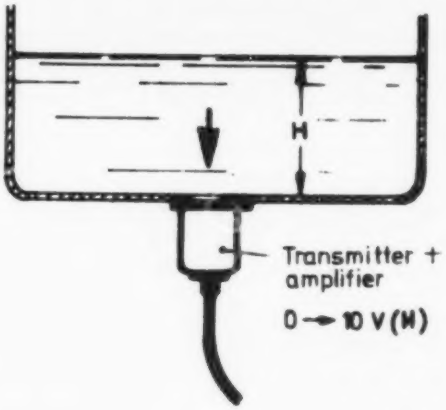


Figure D

4. Pressure level gage with transmitter amplifier

This gage is similar to the instrument described under item 1, but in this case, the amplifier is directly attached to the transmitter. At the output, a voltage of 0 to 10V is released which corresponds to the height of the water level. This transmitter can serve as level meter for the flowmeter, but it is also especially suited as a transmitter for the level indication in large tanks.

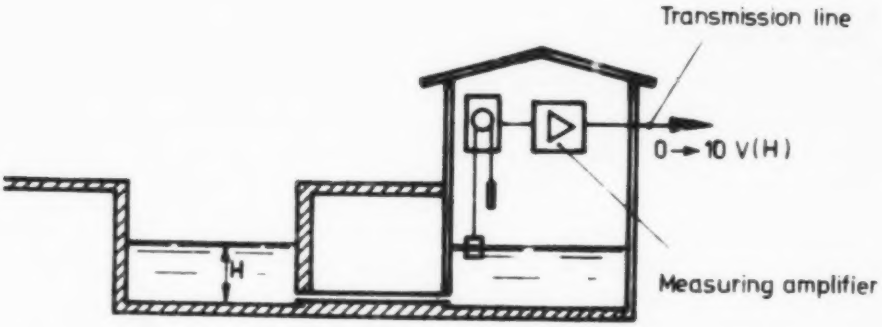


H
Transmitter + amplifier
0 → 10 V(H)

Figure E

5. Float-type level gage

In case where there is a float well existing at the measuring point, the measurement of the water level H can also be effected by means of a float-operated level gage. A potentiometer converts the water level into an electrical signal and applies it to a measuring amplifier. The output of this amplifier is a voltage proportional to the water height H which is led on to a function print for the calculation of the discharge quantity Q. The function print consists of electronic units, so that a mechanical cam is not necessary for the determination of the discharge volume.



Transmission line
0 → 10 V(H)
H
Measuring amplifier

Figure F

Counters - Epic markets a variety of counters ranging from simple, electromechanical devices to fairly complex digital counters and indicators. Typical are the Type 12.000 (F4) Revolution Counter, the Type Z100 counter, and the 12.150 Revolution Indicator. The three-digit F4 counter (Ott 12.000) counts a maximum of 10 pulses per second and is suited for operation with the Ott 10.002 (C31) current meter, which generates a signal pulse at each revolution of its propeller. Two 1.5-volt "D" size batteries serve as the power source and allow up to 48 hours of continuous operation without battery replacement. A stopwatch is used with this device.

The Z100 five-digit counter is capable of measuring the length of pulse cycles from voltage-free transmitters (e.g., current meters), up to a maximum of 20 pulses per second. It is powered by six 1.5-volt single cell batteries, sufficient for about 30 hours of operation, at a rate of eight hours of daily operation.

The 12.150 (F10) revolution indicator provides direct reading of propeller revolutions per second. It features three measuring ranges and has a built-in accumulator with battery charger which can be plugged into a 110/220 VAC power source. The counter is suitable only for measurements where propeller revolutions are at least 1 per second.

Water Level Recorders - Epic offers several water level recorders for use with the Type 22.001 flowmeter as well as with other types of measuring devices. Following is a description of several typical devices. The Model 20.100(X) is a horizontal water level recorder for continuous recording of water levels in still and flowing waters. Drum rotation periods are 24 hours, 8 days, and 32 days.

The Model 21.001 transmitter and 21.356 receiver are remote-controlled water level recorders. The transmitter has an impulse sequencing relay action for telemetering water level data over short and long distances. The receiver is for use with two transmitters, with indication of the water levels and their difference as well as recording of two water levels.

Other models include a 20.250 (R16) vertical water level recorder especially suitable for ground water measurements, and a 20.300(XX) strip chart water level recorder for continuous recording.

Gages - Gages include the Model 24.000 point gage which comes with or without an optical indicator. This device provides exact determination of water levels by means of a pinpoint with reading accuracies of 1/10 mm, 1/1000 ft, or 1/100 inch.

SPECIFICATIONS:

Current Meter (Typical) - Model 10.300

Starting Speed:	0.035 and 0.045 m/sec (.114 and .148 fps)
Measurement Accuracy:	±1.5% (from start of meter up to 0.2 m/s) ±0.5% (0.2 m/s and more linearity error)
Propeller Speed, Maximum:	720 rpm
Remote Transmission of Measured Values:	possible up to 10 km
Dimensions:	
Body	4 cm (1.57 in.)
Length (complete with propeller)	22.2 cm (8.74 in.)
Weight:	No data on 10.300. Weights of other models range from 2.7 to 9.1 kg (6 to 20 lb).

Counter (Typical) - Z100 Counter

Input:	Longitudinal line resistance of measuring cable: 200 ohms (max.) Cross resistance of measuring cable: 1.5 kohm (min.) Load of signal transmitter: 10 mA (max.)
Measuring Range:	Input pulse recurrence frequency: 20 pulses/sec (max.) (a) Preset time. The measuring time can be preset 0.1 sec ...999.9 sec adjustable in steps of 0.1 sec (b) Preset count. The number of pulses can be preset 1 ... 9.999 Range of time measuring 0.1 sec ... 99.999.9 sec

Measuring Accuracy:	(a) Preset time. Measuring time inaccuracy: +0.1 sec (max.). Error caused by measuring procedure: max. -1 pulse (b) Preset count. Error in length of time: ±0.1 sec (max.). Error caused by measuring procedure: 0
Dimensions:	14x12.7x16 cm (5.5x5.0x6.3 in.) (without operating elements and plugs)
Weight:	2.9 kg (6.38 lbs)

Flowmeter/Water Level Meters (Typical)

Measuring Range of Water Level:	0-30 cm (11.8 in.) 0-100 cm (39.4 in.) 0-150 cm (59.1 in.) 0-300 cm (118.1 in.)
Relative Error for Water Level:	0.5%
Possible Shapes of Measuring Channel:	rectangular; triangular; round; venturi-channel
Error of the Water Level (H) - Discharge Quantity (Q) Function (in Transmitter):	±0.3%
Total Error for Discharge Quantity Output:	<±1%
Output Voltage for Water Level:	0-10V (nominal range)
Output Voltage for Q-Output:	0-10V (nominal range) 0-10V (nominal range)
Output Current for Q-Output:	0-20 mA (0-500 ohms)
Power:	220 VAC, 40-60 Hz

PRICES:

Current Meters

10.002	$1,350-1,600
10.200	$825.00
10.300	$870.00

Counters

F4	$200.00
Z100	$925.00

COMMENTS

Rotating element current meters were thoroughly discussed in Section VI and will not be commented upon here.

MANUFACTURER: FISCHER & PORTER CO.
WARMINISTER, PENNSYLVANIA 18974
TELEPHONE (215) 675-6000

PRODUCT LINE:

PRIMARY DEVICES - MAGNETIC FLOWMETERS, FLOW TUBES, FLOAT-ACTUATED FLOWMETERS, PITOT TYPE MAGNETIC FLOWMETERS, PARSHALL FLUMES, AND SLUDGE FLOWMETERING SYSTEMS

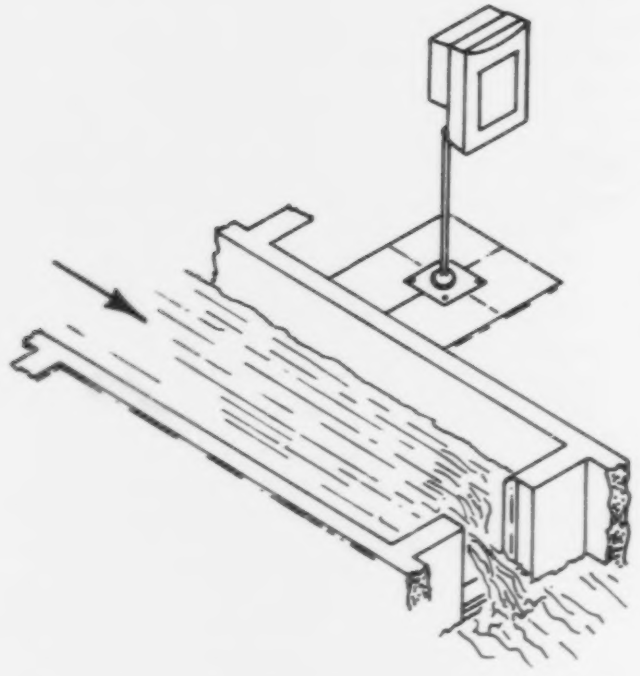
SECONDARY DEVICES - ELECTRONIC TRANSMITTERS (BELLOWS AND MERCURY-ACTUATED), SIGNAL CONVERTERS, ELECTRONIC RECORDERS, AND INDICATORS.

DESCRIPTION:

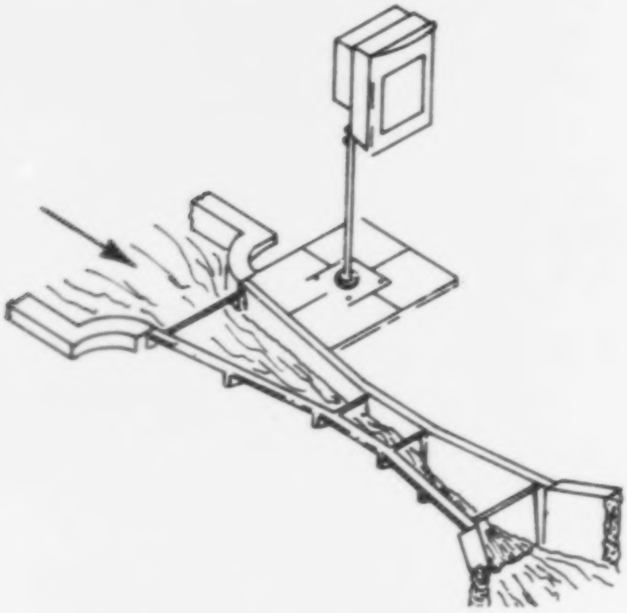
The Fischer and Porter Company offers a broad and diversified line of products for use in various flow measurement applications in the water and wastewater field. The company manufactures a number of different types of flowmeters and flow tubes, as well as a plastic Parshall flume and various signal converters. The company also markets a flowmetering system specifically designed and constructed to continuously measure the flow of sludge. Figure A depicts some typical installations of primary flow measuring devices.

Flowmeters - The type 10F1272 stilling well, float-actuated flowmeter measures flow rate in terms of the stage in flumes, weirs, and other head-area devices. The flowmeter converts vertical changes of float position into corresponding units of liquid flow. The float cable from which the float is suspended is wound on a drum inside the instrument. As the float rises and falls with changes in the liquid level, the float cable winds or unwinds from the drum, causing the drum to rotate. The position of the drum reflects the measurement of the liquid level. The measurement is translated into the desired functional motion for recording, indicating, or integrating through mechanical linkages to a characterized cam attached to the drum. When the flowmeter is equipped with an electric vacuum, or pneumatic transmitter, the measured value can be transmitted as a linear or non-linear signal for remote indicating, recording, or integrating.

The Types 10F1275 and 10F1276 are in-stream, float-actuated instruments that measure the flow rate in terms of the head produced by Parshall flumes, rectangular weirs, or other flumes where head to the 3/2 power is proportional to flow (Type 10F1275), or by triangular weirs (Type 10F1276). The flowmeters transmit an electric time-pulse or DC milliamp signal proportional to the flow to receivers that indicate, record, or integrate the value. These flowmeters are of submersible construction and can be equipped with specially-constructed transmitters for operation in hazardous locations.



TYPICAL INSTALLATION WITH TRIANGULAR WEIR



TYPICAL INSTALLATION WITH PARSHALL FLUME

Figure A

The Pitot-type (probe) magnetic flowmeter (10F1430 series), shown in Figure B, is designed especially for use in water and sewage. It utilizes the Fischer & Porter unique, characterized field principle of electromagnetic induction to produce an AC signal directly proportioned to the flow rate. Using this device, liquid flows can be measured in large rectangular, circular, or irregularly shaped pipes. It is to be noted that it is strictly a velocity-sensing device, and measures only the flow velocity at one specific point of the cross-sectional flow diameter, although that point is fairly large since the probe inside diameter is about 25 cm (10 in.). The flowmeter can be installed completely submerged in the fluid stream inside the pipe while secured at the end of a support suspension. The smallest recommended pipe line size for the insertion of the flowmeter is slightly less than one meter (36 in.). An optional feature of this flowmeter is its bi-directional flow measurement capability.

Another flowmeter in the Fischer & Porter line is the Short Form Characterized Coil (SFCC) Design Model 10D1430A (Figure C). This electromagnetic measuring device operates on the same principle as the Pitot-type Model 10F1430. The SFCC meter differs from conventional electromagnetic flowmeters in that it uses a light weight coil encased within the liner of a metering tube instead of a heavy external field coil. Meter sizes range from 7.62 to 243 cm (3 to 96 in.) and weigh from 43 to 2,268 kg (95 to 5000 lbs). Designed for liquids, the meter is reported to be unaffected by density or viscosity or by normal upstream or downstream piping configurations. In addition, electrode cleaning is available upon request for both standard and accidental submerged ("splashproof") designs. The meter can be mounted in any attitude (although vertical is recommended) in the pipeline. The manufacturer states categorically that full pipe flow conditions must exist in order for the meter to obtain accurate measurements.

Fischer and Porter also manufacture long form magnetic flowmeters (Type 10D1416A), which have been in production for almost 20 years. They are available in sizes from 15 to 61 cm (6 to 24 in.) as standard and may be ordered in sizes up to 198 cm (78 in.), but the SFCC design is recommended for the larger sizes. This type has been in service so long that it serves as a dimensional standard in many plant-layout specifications and guides.

Common features of all Fischer and Porter magnetic flowmeters include very high accuracy, very stable operation, extremely sensitive operation (can measure liquid flow with conductivities as low as 0.1 micromho per centimeter), and direct digital computer compatibility. Electrodes are field replaceable with no loss in accuracy and no need for recalibration.

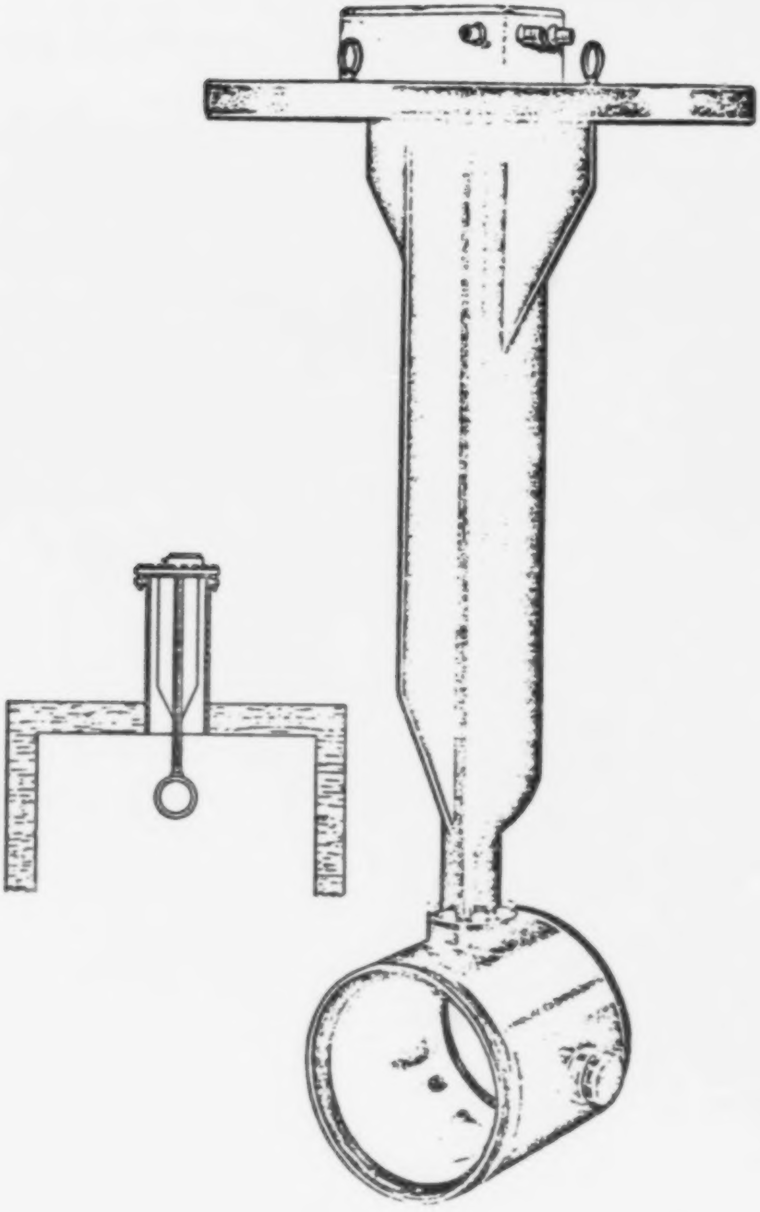


Figure B

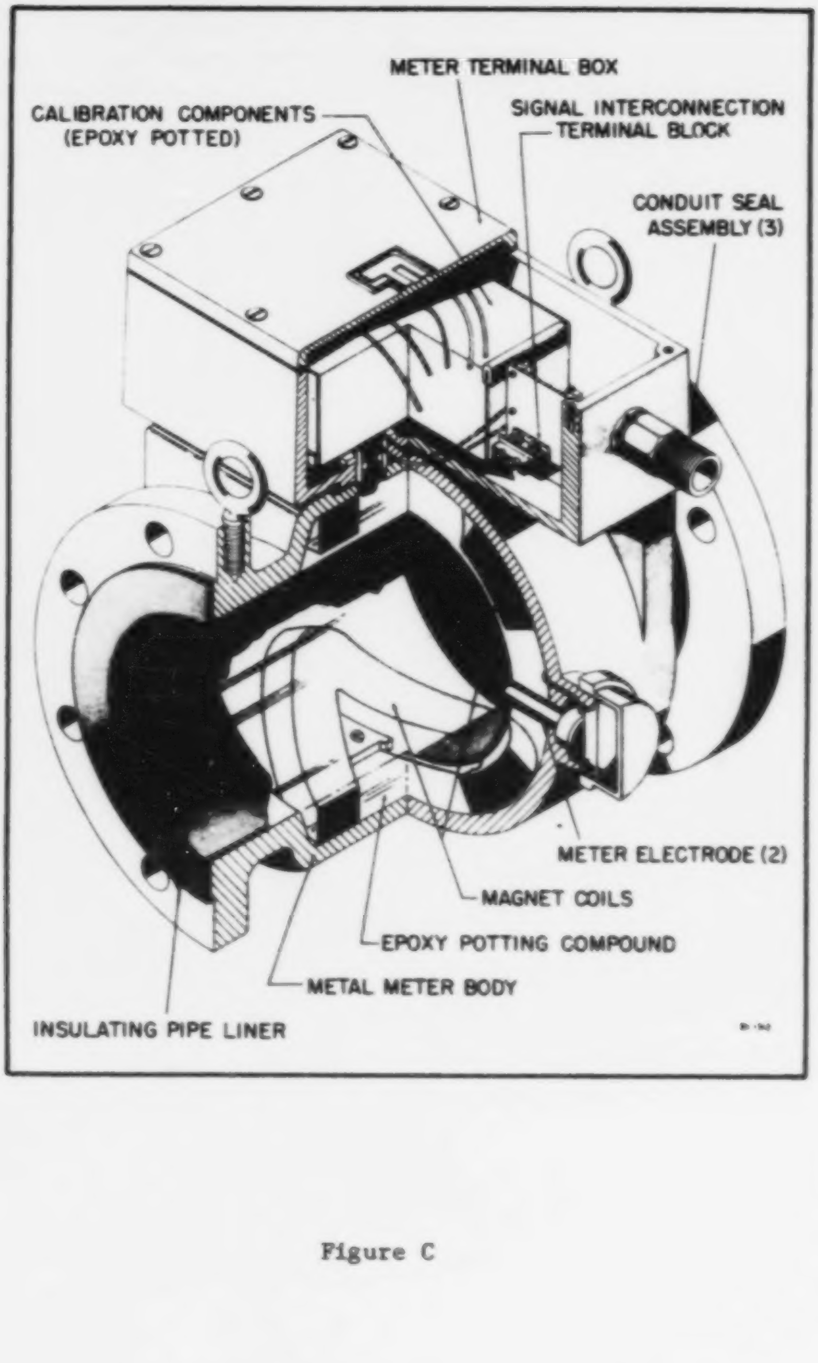

METER TERMINAL BOX
CALIBRATION COMPONENTS (EPOXY POTTED)
SIGNAL INTERCONNECTION TERMINAL BLOCK
CONDUIT SEAL ASSEMBLY (3)
METER ELECTRODE (2)
MAGNET COILS
EPOXY POTTING COMPOUND
METAL METER BODY
INSULATING PIPE LINER

Figure C

Parshall Plastic Flume - The Type 10F1940 Parshall flume is a one-piece plastic unit designed for the metering of liquids in open channels. Because of its unbroken flow lines which present no obstructions to cause build-ups of debris, the flume is particularly well suited to the measurement of liquids containing settleable solids. The F&P flume is available in various standard throat widths ranging from 2.54 cm (1 in.) to 3m (10 ft). The flume is constructed of corrosion-resistant, lightweight molded fiberglass reinforced polyester with integral stiffening ribs to make the unit self-supporting and eliminate external bracing. Options include integral stilling wells and staff gages.

Flow Tubes - Fischer and Porter Series 10F1070 cast iron flanged flow tubes (Figure D) are differential-pressure producing, primary metering devices of a proprietary design which, it is claimed, produce a high differential with minimum head loss (2-4%). Tubes are available for nominal line sizes from 10.2 to 61.0 cm (4 to 24 in.). Four standard throat sizes can be provided in each line size. The tubes are constructed of high tensile cast iron with the throat sections available in bronze or stainless steel.

The 10F1060 plastic insert type flow tubes (Figure E) contain outlet cones constructed of polyester plastic, reinforced with 30 percent fiberglass by weight and throats of either bronze or stainless steel. Tubes are available for nominal line sizes from 10.2 to 91.4 cm (4 to 36 in.). Four standard throat sizes can be provided in each line size.

Sludge Flowmetering Systems - The patented Fischer & Porter Model 10D1416/18C(s) Magnetic Flowmeter is designed to continuously measure the flow of sludge. This design uses the electromagnetic induction field of the flowmeter coils to produce an eddy current effect in the aluminum metering tube. The eddy currents produce continuous heating within the tube while simultaneously transferring the heat through a "process-wetted" liner to prevent sludge and grease buildup. To complement this capability and provide greater accuracy of measurements, the manufacturer recommends the use of an optional feature - an ultrasonic electrode cleaning device. The output signal from the Model 10D1416/18C flowmeter, representing sludge flowrate, can be received by either a 51-1100DC series circular chart electronic recorder or indicator, or a 50ED4000 or 50SF2000 series signal converter.

Flow Transmitters - The Fischer and Porter flow transmitters, Types 1451RB and 1453RB, are bellows-actuated instruments designed to produce a 4 to 20 mADC linear signal proportional to changes in rate of flow through differential producers. The differential pressure is detected at the metallic bellows of the transmitter which uses mineral oil as a fill fluid. A torque tube assembly within the meter housing responds to differential pressure changes and its movement is transmitted by an operating spindle to a linear variable differential

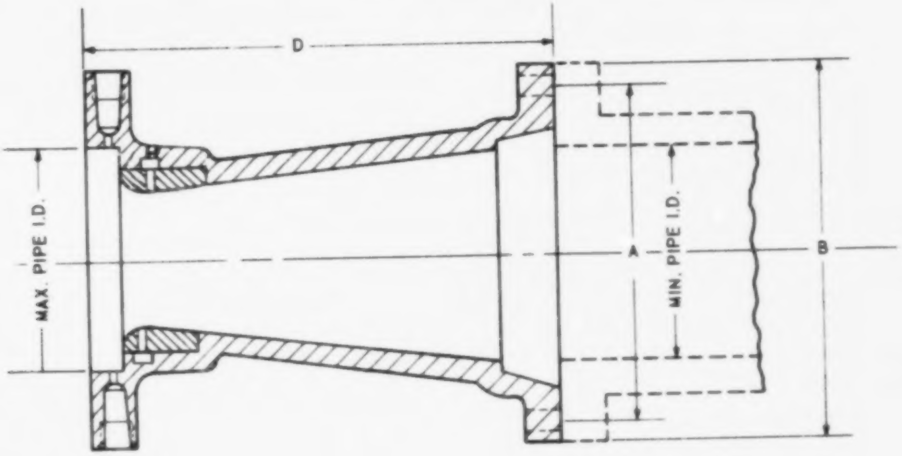

D
MAX. PIPE I.D.
MIN. PIPE I.D.
A
B

Figure D

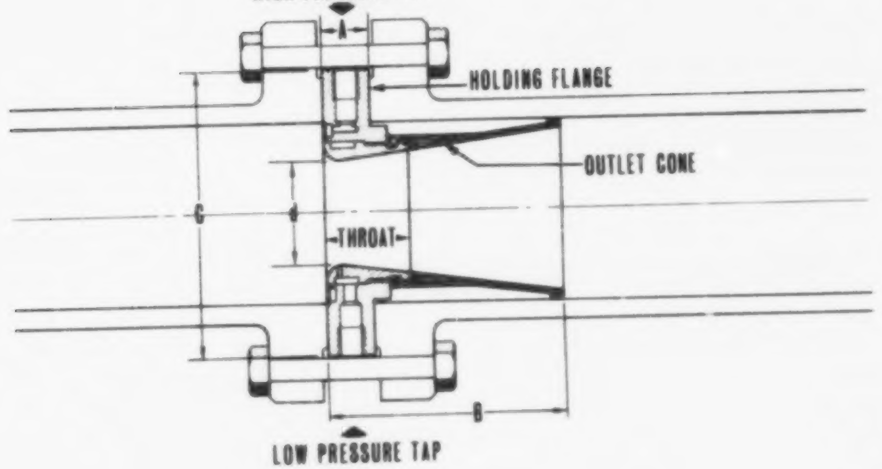

HIGH PRESSURE TAP
A
HOLDING FLANGE
OUTLET CONE
C
d
THROAT
B
LOW PRESSURE TAP

Figure E

transformer (LVDT). The output of the LVDT is received by solid state electronic circuitry for extraction of the square root function of the differential to produce an instrument output signal proportional to flow.

The Type 1451RE and 1453 flow transmitters are mercury manometer-operated instruments which produce a signal similar to that of the bellows-operated transmitter. However, the differential pressure is detected at the mercury-filled wells of the transmitter. A float in the low pressure well responds to the mercury level changes and its movement is transmitted by an operating spindle to a LVDT as is done in the bellows-actuated transmitter.

Signal Converters - The 50SF2000 Series magnetic flowmeter signal converter is a completely solid-state unit with integrated circuitry. The Converter is capable of receiving a low level AC signal either directly from an F&P magnetic flowmeter or indirectly via an F&P low conductivity preamplifier. This signal can be converted into an analog DC current, a high-frequency pulse, or a low-frequency scaled pulse. The converter is suitable for pipe or wall mounting, and as such, can be provided with a flow rate meter and seven digit counter. Features include automatic dual range, adjustable damping, and continuous and automatic quadrature rejection.

Circular-Chart Electronic Recorder or Indicator - The Type 51-1102DC circular chart recorder or the 51-1101DC segmental indicator complete with an in-case "Mag/I" Converter is designed to receive the flow signal from various Fischer and Porter magnetic flowmeters or from the F&P low conductivity preamplifier. The instrument is a solid-state, null-balance, servo-operated potentiometer that uses a unique driving motor called a "TORQ-ER" and a contactless feedback element called a "flux bridge". Either instrument is capable of receiving one or two process variable inputs. Optional controllers, integrators, or transmitters can be included within the instrument case. Fischer and Porter also manufacture many other primary devices (e.g., turbine meters) and secondary devices (transmitters, receivers, transducers, relays) in both pneumatic and electronic form.

SPECIFICATIONS:

Type 10F1272 Float Actuated Flowmeter

Operating Limits:	Between 10.16 cm (4 in.) and 76.2 cm (30 in.) of head at maximum travel
Accuracy:	Float travel is within ±0.15 cm (1/16 in.) of actual liquid travel

Power:	120 VAC, 60 Hz, Single Phase
Dimensions:	Varies according to configuration used and customer requirements
Weight:	40.5 kg (90 lbs)

Types 10F1275 and 10F1276 In-Stream Flowmeters

Range:	Type 10F1275: Can be used on flumes 7.62-305 cm (3-120 in.) wide and on rectangular weirs 30.5-305 cm (12-120 in.) wide. Type 10F1275A: Can be used for head ranges from 0-15.24 cm (0-6 in.) and 0-40.1 cm (0-15 in.). Type 10F1275B: For head ranges from 0-30.5 cm (0-12 in.) and 0-76.2 cm (0-30 in.). Type 10F1276: For triangular weirs, Type 10F76A covers head ranges from 0- to 25.40 cm (0-10 in.) and 0 to 45.7 cm (0-18 in.).
Output:	Electric Time Pulse - DC pulses on leased or private pair. Electric DC Milliamp Signal - 4 to 20 mADC over two-wire line.
Accuracy:	±20% over 2:1 range (standard)
Power:	120 VAC, 60 Hz, Single Phase
Dimensions:	Varies according to configuration used and customer requirements
Weight:	13.5 kg (30 lbs)

10F1430 Series Pitot-Type Magnetic Flowmeter

Accuracy:	±1% for max flow velocity of 0.91 to 9.42 m/s (3 to 31 fps) or ±2% for max flow velocity of 0.30 to 0.91 m/s (1 to 3 fps)
Repeatability:	0.5% of full scale
Output:	
Signal	50 or 60 Hz AC, approx 0.2 millivolts (rms) per foot (30 cm) per second.

Reference	50 or 60 Hz AC, approx 5 to 6V rms
Power:	117 VAC, ±10%, 50 or 60 Hz
Dimensions:	Meter - 25.4 cm (10 in.) nominal inside diameter Support Suspension Length: 4.5m (15 ft) maximum; 0.3m (1 ft) minimum

SFCC Model 10D1430A Flowmeter

Accuracy (including readout):	±1% Full Scale, 0.91 - 9.37 m/s (3-31 fps) ±2% Full Scale, 0.30 - 0.91 m/s (1-3 fps)
Repeatability:	±0.5% of Full Scale
Power:	117 VAC ±10%, 50 or 60 Hz, 17-910 watts (depending on meter size).
Dimensions and Weight:	Refer to preceding description of this flowmeter

Type 10F1940 Plastic Parshall Flume

Free Flow Discharge:	0.38 to 130 MLD (0.1 to 494 MGD)
Max Head:	20.3, 25.4, 45.7, 63.5 and 76.2 cm (8,10,18,25, and 30 in.)
Weight:	11.25 to 1350 kg (25 to 3000 lbs).

10F1060 Series Plastic Insert Flow Tubes

Accuracy:	Within 1% of rate (uncalibrated tubes) Within ±0.5% of rate (calibrated tubes)

Types 1451RB and 1453RB Bellows-Actuated Electronic Flow Transmitter

Range:	5:1 (20% to 100% of max flow rate)
Accuracy:	±0.50% of max flow rate (Standard); ±1.0% of actual flow rate (optional)
Input:	Differential pressure from flow through a differential producer. Bellows sensing element available in ranges of 0.5m (20 in.)

Output:	4-20 mADC into 0-750 ohms.
Power:	120 VAC ±10%, 50/60 Hz or 24 VDC
Temperature:	4° to 52°C (40° to 125°F)
Power:	120 VAC ±10%, 50/60 Hz or 24 VDC

Series 50SF2000 Signal Converter for Magnetic Flowmeters

Input Signal:	From any F&P Magnetic Flowmeter.
Output:	
Electric Analog	4-20 mADC into 0-1000 ohms (0-16 mADC optional) 10-50 mADC into 0-400 ohms (0-40 mADC optional)
Dual Range Selection	Ranges are fixed for ratios of 2:1, 4:1, 6:1, 8:1 and 10:1. Range is to be specified when ordering. Lowest full scale value is 0.9 m/s (3 fps).
Accuracies:	(including flow transmitter); Analog and/or pulse - ±1/2% full scale 0.9 to 9.3 m/s (3 to 31 fps); ±1% of full scale from .03 to 0.9 m/s (0.1 to 3 fps).
Repeatability;	0.25% of full scale.
Response Time:	Digital: 1 second Analog: 1 to 80 seconds, adjustable. (10 seconds standard)
Power:	117 VAC ±10%, 50 or 60 Hz ±5%, 12 watts (max) @15 VA

Type 51-1100DC Circular Chart Electronic Recorder or Indicator for Magnetic Flowmeters

Inputs:	Accepts signals from all F&P Magnetic Flowmeters
Output:	
Analog	4-20 mADC into 750 ohms or 10 10-50 mADC into 300 ohms external load.
Unscaled Pulse	10 kHz, 15 VDC, 8 microsec pulse width into 2000 ohms or greater.

Accuracy:	±0.5% of full scale for analog and pulse outputs on all models including single and dual ranges.
Repeatability:	0.2% of span
Temperature:	4° to 52°C (40° to 125°F)
Power:	120 VAC ±10%, 50-60 Hz ±5%, 45 watts
Weight:	Approximately 18.6 kg (40 lbs) for single pen unit.

MANUFACTURER: CARL FISHER AND COMPANY
DIVISION OF FORMULABS, INC.
529 WEST FOURTH AVENUE
P. O. BOX 1056
ESCONDIDO, CALIFORNIA 92025
TELEPHONE (714) 745-6423

PRODUCT LINE: FLUORESCENT DYES

DESCRIPTION:

This company has long been active in the chemistry of color and produces a number of fluorescent dyes that can be used as tracers in either color-velocity or chemical dilution flow studies. Two colors are standard; fluorescent red (maximum absorbance point on a spectrophotometer is approximately 558 mμ) which is more commonly used, especially if the water contains some yellow, and fluorescent yellow/green (maximum absorbance point on a spectrophotometer is approximately 494 mμ) which is recommended for use when the water contains large quantities of silt.

The dyes appear to be non-toxic in the levels used for flow measurement. For example, the FDA has established a level of daily ingestion of 0.75 mg per day for fluorescent red. Considering the normal human daily consumption of water this would equal approximately 370 parts per billion, at which concentration the water would have a bright fluorescent red color. Instrumental detection limits are around 1 part per billion.

The fluorescent dyes are available in a number of solid forms including tablets (2.5 gm), cakes (55 gm), donuts (0.33-1.17 kg), and logs 7.6 cm (3 in.) diameter and up to 1.2m (4 ft) long (8.6 kg).

PRICES:	Tablets	$0.07 each (2,600 quantity orders)
	cakes	0.90 each (5,000 quantity orders)
	donuts (small)	4.75 each
	donuts (large)	10.00 each
	logs	24.00 per foot

COMMENTS:

These dyes appear suitable for a number of storm or combined sewer flow studies. The manufacturer will offer specific information on such applications upon request.

MANUFACTURER: FLOW TECHNOLOGY, INC.
4250 EAST BROADWAY ROAD
PHOENIX, ARIZONA 85040
TELEPHONE (602) 268-8776

PRODUCT LINE: TURBINE FLOWMETERS OF VARIOUS CONFIGURATIONS PLUS A COMPLETE LINE OF SECONDARY INSTRUMENTATION INCLUDING SIGNAL CONDITIONERS, PULSE RATE CONVERTERS, FLOW RATE MONITORS, ETC.

DESCRIPTION:

Flow Technology, Inc. manufactures "standard line" axial-turbine flowmeters in sizes from 0.6 cm (1/4 in.) to 0.6m (2 ft) with standard ranges of 10:1 which can be extended to as much as 250:1 in some cases. They also manufacture a tangentially-driven turbine, the "omniflow" which is capable of measuring extremely low flow rates. Neither of these appears suitable for wastewater applications, and they will not be described further.

Flow Technology manufactures point velocity sensing elements called "Turbo-Probes". The "Turbo-Probe" family of turbine flow transducers utilizes a small axial-flow turbine sensing element positioned in the flow stream of a large duct, pipe, or channel by means of a strut. The sensing element is a small, freely-suspended turbine flowmeter unit within its own open-ended cylindrical capsule. As this turbine turns under the force of the flowing fluids, its rotation produces a series of electrical pulses in a pickoff located in the strut. The pulse rate or frequency of this electrical signal is directly proportional to the velocity of the fluid passing through the capsule. This pulse output can be fed to appropriate electronics to count, totalize, or display the flow velocity of rate in various engineering terms - feet per minute, gallons per minute, meters per second, cubic meters per hour, etc. This output can also interface with industrial process control systems or on-line computers. This family of flowmeters has found applications both as portable insertion probes and as permanently-installed units. Figure A depicts a typical configuration.

An outstanding feature of the "Turbo-Probe" series is the economy achieved when it is necessary to make flow measurements in pipes, ducts, or channels of very large size. The exorbitant cost of full-bore turbine flowmeters far outweigh their favorable high-accuracy characteristics in such applications. The response of such large turbines can be low because of the high mass of the rotors. However, in such applications, a "Turbo-Probe" installation with its small turbine can result in considerable cost savings at little sacrifice of accuracy and considerable gain in response. If the velocity profile in the flow channel is known, the fluid velocity data can be directly related to flow volume. Absolute volumetric flow accuracies of ±0.5 percent have been achieved. The accuracy of velocity measurements are on the order of ±0.25% under field conditions.

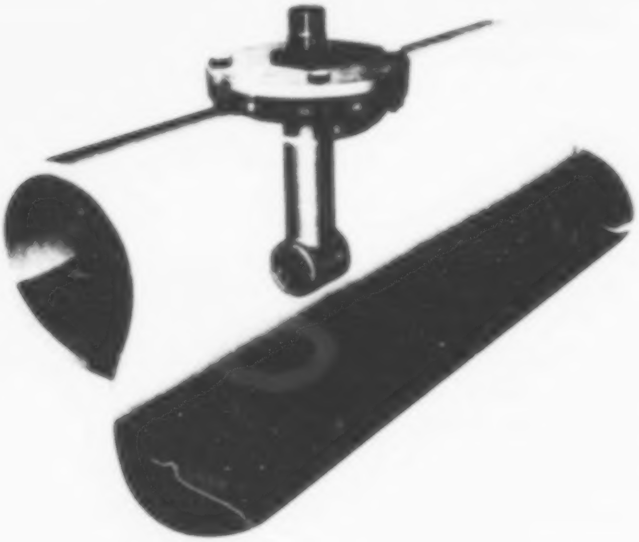


Figure A

"Turbo-Probe" units can be fabricated from a wide variety of materials capable of withstanding the most difficult industrial environments. A retractable version of this flow velocity sensor called "Retracto-Line" is also offered for use in large diameter pipelines.

Secondary Elements - Model LFP-200 is a low flow, offset signal conditioner. Turbine flowmeters designed for low flow rates exhibit a linear frequency output as a function of flow rate, but also exhibit a zero offset that appears as a non-linearity with a standard flow rate monitor or flow totalizer. Flowmeters designed for higher flow rates also exhibit this zero offset characteristic when there is an increase in the viscosity of the fluid being measured or when the flow range is extended below the normal minimum for the particular design.

The LFO-200 is designed to correct this zero offset by injecting into the flowmeter output pulse signal a predetermined frequency - dependent upon the design of the flowmeter - that allows the flow-versus-frequency characteristic curve to intersect the zero point, thus eliminating the zero offset. Because turbine flowmeters have a minimum flow rate and do not respond down to zero flow rate - there is a point where flow exists but the turbine rotor stops or becomes highly non-linear in its rotation - the LFO-200 incorporates a circuit to cut off the frequency output at a predetermined minimum output frequency. Because of the cutoff feature, there is no output from the LFO-200 when the rotor is turning below a given rate or when the rotor is stopped. The LFO-200 therefore increases the accuracy of low flow indications and permits the use of less-expensive frequency-to-analog flow rate monitors and flow totalizers. The LFO-200 is a solid-state unit normally packaged in a heavy-duty steel JIC box with input, output, and power supply connections made through MS-type connectors. Other types of enclosures and connectors are available on special order.

Model LFA-300 is a range extending amplifier. Turbine flowmeters with normal pickoffs experience a magnetically-induced drag on the turbine rotor. This drag force causes severe non-linearity at very low flow rates. To eliminate this low-flow rotor drag, an "active" pickoff coil must be used. The Range Extending Amplifier LFA-300 is the necessary electronic unit for use with such an active pickoff and supplies an amplified pulse output with the same frequency as the input signal. The LFA-300 can extend the operational range of turbine flowmeters from their normal 10:1 ratio up to a ratio of as much as 250:1. In the low flow ranges, because of the zero offset phenomenon, the output will be non-linear; however, it will be a repeatable non-linearity. The LFA-300 is a solid-state unit normally packaged in a heavy-duty steel JIC box with input, output, and power connections made through MS-type connectors.

SPECIFICATIONS:

"Turbo-Probe"	Model FTP-A	Model FTP-B
Velocity range span	1.5-30.5 m/s (5-100 fps)	0.09-30.5 m/s (0.3-100 fps)
Velocity range ratio	10:1 standard	10:1 standard
Turbine head dimensions	1.9 cm (3/4 in.) dia & length	3.2 cm (1.25 in.) dia & length
Linearity	±0.5%	±0.5%
Repeatability	up to ±0.1%	up to ±0.1%

Model LFO-200

Signal Input:	Frequency range - 1 to 3000 Hz. Input level - 5 to 20V pulse
Signal Output:	Frequency - Input frequency from flowmeter plus injection frequency

	Output level - 5V peak-to-peak pulse
Internal Adjustments:	Offset Frequency Range - 0.5 to 25 Hz.
	Cutoff Frequency Range - 1 to 25 Hz.
Power Requirements:	115V 60 Hz. Less than 5 watts
Dimensions:	15.4x10.2x7.6 cm (6x4x3 in.)

Model LFA-300

Input:	1 to 3000 Hz from turbine flowmeter active pickoff
Output:	10V peak-to-peak pulse into 10K load, frequency identical to input frequency
Power:	24 VDC 50 mA, 115V 60 Hz optional
Dimensions:	15.4x10.2x7.6 cm (6x4x3 in.)

COMMENTS:

These turbine point velocity sensors may find some application in attended use in wastewater flow surveys. The range-extending option appears attractive, and their sensitivity should allow velocity profiling and the like to be accomplished fairly well. They do not appear suitable for unattended use or fixed installations, however.

MANUFACTURER: FLUMET CO.
P.O. BOX 575
WESTFIELD, NEW JERSEY
N.Y. OFFICE: TELEPHONE (212) 227-6668

PRODUCT LINE: PALMER-BOWLUS FLUMES

DESCRIPTION:

FLUMET manufactures a "trapezoidal throat venturi weir" that has evolved from the Palmer Bowlus flume. It is comparable to a Parshall flume in accuracy and in minimum restriction to flow, but the throat area design avoids the necessity for the rectangular approach section. The trapezoidal section is hydraulically like circular channel flow and establishes a usable energy head. The Flumet units are three-piece flumes designed for installation where through-type manholes exist on normally sloped lines. All Flumet flumes will pass solids up to 7.62 cm (3 in.) spherical equivalents.

Where sewers exist, and to permit surveys, the standard hexagonal units can be placed under flows of 50 percent depth. The flume is placed near the manhole out-fall. The channel should be "U" shaped, with side walls up to 90 percent of the line diameter; if too shallow, temporary walls can be created. To install, the base (or sill casting) is dropped in place, and then the side walls are locked in and dropped back against the walls at a controlled angle; a template is provided for checking. Grouting is seldom required, and small leaks are often quickly sealed by the fibrous particles of waste flow, due to the ribbed back design.

Use of a stilling well and large area float will produce maximum head accuracy. The flume is compatible with various secondary metering instrumentation.

Flumet's eccentric flume reducer is designed for large conduits (waste collector lines) whose diameter is based on future flows, but where, initially, lower-volume flows must be metered. The Flumet split eccentric reducer can be installed, then dismantled and removed later, under flow. These modules are molded of acid-resisting, glass resin and fiber laminates, made in 68.6 centimeter (27 inch) lengths to pass through manhole frames. Field installations can be made in 1-1/2 to 2 hours.

SPECIFICATIONS:

Accuracy:	3% (optimum)
Sizes:	15.2 to 76.2 cm (6 to 30 in.) for standard sewer piping.

Flow Capacities: From 1.32 MLD (0.350 MGD) for 15.2 cm size to 53.0 MLD (14 MGD) for 68.6 cm sizes

Length: 27.9 to 132 cm (11 to 52 in.)

Weight: 5.4 to 79.4 kg (12 to 175 lbs)

PRICES: Approximately $200-$500 for a basic insert flume.

COMMENTS:

Palmer-Bowlus type insert flumes were thoroughly discussed in Section VI and no further comments will be made.

MANUFACTURER: THE FOXBORO COMPANY
FOXBORO, MASSACHUSETTS 02035
TELEPHONE (617) 543-8750

PRODUCT LINE:

PRIMARY DEVICES - TARGET, ELECTROMAGNETIC, AND TURBINE FLOWMETERS.

SECONDARY DEVICES - DIFFERENTIAL PRESSURE TRANSMITTER, MERCURY-TYPE FLOWMETERS, LIQUID LEVEL TRANSMITTERS, AND VARIOUS FLOW INTEGRATORS, RECORDERS, ETC.

DESCRIPTION:

Foxboro is a leading, worldwide supplier of instruments and systems for process management and control. It has more than 60 years of specialized experience in the production of measurement, recording, and control devices and systems designed to measure, handle, and control liquid flows, liquid levels, pressure, etc. This varied line of instrumentation ranges from meters, recorders, and indicators to complex digital control systems fully equipped with computers and other data processing equipment.

Primary Devices

Target Flowmeters - Foxboro manufactures both pneumatic and electronic target flow transmitters. These transmitters produce repeatable force-balance measurement and transmission of both clean fluids and fluids of a heavy, conductive and non-conductive viscous nature (such liquids include slurries up to 1500 psi, even in high viscosity regions where pipe Reynolds numbers are 2000 or less). Because target-type devices are generally unsuitable for storm or combined sewer flows, they will not be discussed further.

Electromagnetic Flowmeters - Based on more than 16 years of experience in magnetic flow measurement, Foxboro has recently introduced completely redesigned electromagnetic flow instruments. Nearly any electrically conductive liquid (up to 160°C) can be accurately metered (e.g.: dirty, viscous, corrosive, or abrasive slurries; solids bearing; turbulent; etc.). Both industrial and municipal water and waste treatment plants utilize Foxboro magnetic flow systems. Typical applications include plant-effluent, activated sludge, raw sewage, etc.

Representative of this product line is the Series 2800 flow transmitter, which operates at line sizes of 2.54 to 30.5 cm (1 to 12 in.)*. The magnetic flow transmitter responds to liquid velocity only. It generates an AC voltage directly proportional to fluid velocity and, hence, volumetric-flow rate. The transmitter is unaffected by process variations in density, viscosity, line pressure, vibration, or temperature. The transmitter is accurate with liquids as low in conductivity as 2 micromhos per centimeter. System accuracy to ±0.5% of full scale can be achieved. The unit operates in horizontal, vertical, or any angular position as long as the electrodes are in the same horizontal plane. Transmitters are available with flow tubes of fiberglass or stainless steel lined with TFE or polyurethane. Coils are external to the flow tube for accessibility and protection from process and environmental conditions.

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* Other transmitters are available for line sizes up to 122 cm (48 in.)

The 2800 Series transmitter contains no converter-type circuitry but can be equipped with the Foxboro 696A Series converter to obtain direct totalization of liquid flow.

Turbine Flow Transmitters - These devices measure volumetric flow. The liquid stream passes through a rotating multi-blade rotor. As the rotor turns, a pickup coil induces a pulse of voltage (as each blade passes). The pulse rate is proportional to volumetric flow rate, each pulse being a measure of a discrete volume of liquid. Because it is generally considered to be unsuitable for sewage and waste-water applications, the turbine meter will not be discussed further.

Secondary Devices

Force-Balance Transmitters - This device uses the Foxboro-developed differential pressure cell transmitter mechanism to measure the pressure differential produced by any one of a variety of primary devices (e.g., venturi tubes, orifices, etc.) and transmits to remote receivers (pneumatic or electronic) any variable which is a function of pressure, flow, liquid level, density, or temperature.

Mercury-Type Flow Meter - This device gives precise metering of liquid, steam, and gas flows at pressures up to 2500 psi, and is suitable for use with a number of differential-pressure type primary devices. They are normally equipped with 30.5 cm (12 in.) circular chart recorders.

Flow Integrators - These devices indicate the number of gallons or other units of fluids passing through a specific point in a given time period. The quantity is shown on a 6- or 8-digit counter. They are available for simple integration, remote integration in both electronic and pneumatic systems, pulse duration, and continuous integration. They also have provisions for batching, switching, etc.

Electromagnetic Flow-To-Current Converter - The 696A Series converter accepts the generated voltage from the electromagnetic flow transmitter and transmits a standard DC signal to electronic receivers. Outputs can be either 10 to 50 mA or 4 to 20 mA. The signal is directly proportional to (linear with) flow rate. A scaled pulsed output is also available for direct flow totalization in engineering units.

Other Electromagnetic Flow Measurement Instruments - Other Foxboro instrumentation in this product line includes the 9650 Series Dynalog Recorder, which receives and records the generated voltage output of the transmitter on a 30.5 cm (12 in.) circular chart or provides large dial indications. Foxboro also manufactures a wide line of pneumatic and electronic controllers, recorders, integrators, and counters.

Liquid Level, Density, and Interface Instruments - Foxboro instrumentation provides various approaches to liquid level measurement. Included are air bubble systems, submerged diaphragm boxes, float and cable systems, direct-connected static head systems, diaphragm and mercury manometer elements, etc.

COMMENTS:

The devices offered by Foxboro have been thoroughly discussed elsewhere and will not be further described here.

MANUFACTURER: GM MFG. AND INSTRUMENT CORPORATION
2417 THIRD AVENUE
NEW YORK, NEW YORK 10451
TELEPHONE (212) 665-1601

PRODUCT LINE: CURRENT METERS AND ACCESSORIES

DESCRIPTION:

This firm manufactures a number of hydrographic current meters and accessories, a few of which will be described here. "GEMWARE" current meters are supplied with light-weight propellers, specially shaped to operate at all rated water flows with a minimum of friction, to ensure highest registration accuracy. Their hydrodynamic forms were developed after many towing tank trials. They are electrical switch-type meters, producing either a mechanical contact by a gear or a frictionless contact by a magnet. The contacts may be registered by earphones, buzzers, blinking lights, digital counters, digital printers, strip chart event recorders, etc.

For deep or fast water, the current meter is usually suspended by its electrical cable with a hydrodynamic weight at the end. For shallow water operation, it may be attached to a wading rod. When using current meters for measuring water flow in conduits or pipes, etc., adjustable holders for mounting can be furnished. Differently pitched, hydrodynamically shaped, and vane type propellers have been specifically developed for measurements of slow, medium, and fast currents. They are of lightweight metal alloys, surface treated to better withstand corrosive action, and are carefully hand finished and polished. Each is individually tested with its current meter and furnished with a calibration certificate; with a graph, an accuracy of 0.025% may be expected. The propeller shafts rotate on precision bearings and almost all meters are sealed or protected against water entrance, either mechanically or by an oil bath. "GEMWARE" current meters are shipped in sturdy, compartmented, wooden carrying cases with accessories, spare parts, and tools.

The No. 232WA060 "GEMWARE" Mechanical Contact Current Meter, with a 25 cm (10 in.) pitch x 12 cm (4.7 in.) diameter contoured propeller can measure flow rates over a range of 0.2 to 5 m/s (0.6 to 17 fps). Exchangeable gears provide electrical contact for either 10 or 20 turns of the propeller. On special order, other gears can be supplied to make contact for each 5 propeller revolutions or to indicate reversal of flow direction. The meter may be affixed to a wading rod or may be cable suspended with a self-aligning, hydrodynamic-shaped weight and tail vane.

The No.232WA240 "GEMWARE" Magnetic Contact Current Meter (Figure A) is the modern concept of a hydrodynamically constructed meter which is reliable for water speed measurements in rivers, dams, reservoirs, etc. It is streamlined and watertight and has a hermetically-sealed, magnetically-attached switch electrically connected to a watertight jack for the plug-in electrical cable. There are no exposed gears or components to wear or corrode nor can the electrical contacts become fouled, as with the Price current meter. It may be used in silt-laden waters without damage as all the components, except the propeller, are sealed within the one-piece, machined housing. The propeller can be supplied with a special coating to improve its hydrodynamic efficiency and resist the possibility of corrosion. This meter is extremely sensitive to waters flowing at all speeds and accurately measures flow over a range of 0.2 to 5 m/s; its 25-cm pitch, lightweight propeller is supplied with an individual calibration to assure accuracy for flow calculations. It is reliable and is unconditionally guaranteed as to quality and workmanship. The meter is furnished in a sturdy, hinged-cover, wooden case with compartments for the current meter, spare parts, 10m (33 ft) long reinforced lowering cable, lubricating oil, and tools. The complete apparatus with accessories and storage case weighs 6 kg (13 lbs); the case dimensions are 35x21x14 cm (14x8.5x 6 inches).

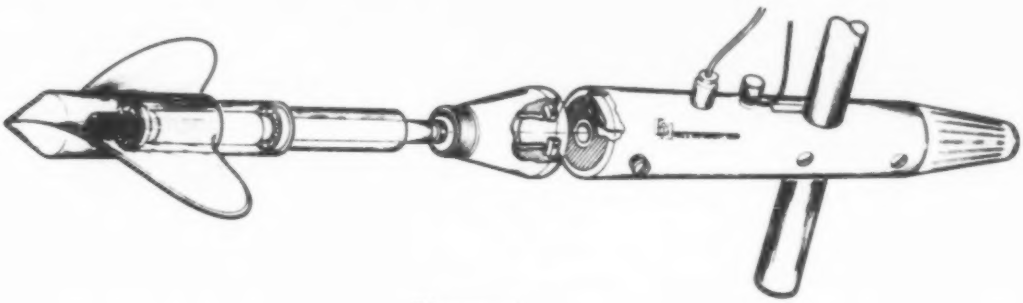


Figure A

The No. 231WA300 "GEMWARE" Current Meter is an improved Ekman type meter. This is a mechanical instrument and is operable at any depth by the use of messengers. The patented split bearing system allows fastening of one or more meters at any point on the wire. As it is messenger operated, it can even be placed on the wire between water bottles or other messenger-actuated instruments. Accidental damage is minimized by rugged construction and the use of metal guards to protect moving parts. All materials used are non-magnetic and the entire instrument is silver plated. A spring-loaded, flared, split tube is provided to lock the propeller until ready to start the measurement. At that time, a messenger is dropped down the wire to actuate the split tube release which rotates, horizontally, about 45 degrees, giving the propeller a short push to overcome any starting inertia when measuring very low speed currents. After a predetermined time period elapses, a second messenger is dropped to release a spring-tensioned short rod, which then also rotates on a horizontal plane and passes between the propeller blades to stop further rotation. With every 33 revolutions of the propeller one metal ball falls through a tube in the dial counter gear box and into a trough on a freely-moving, pivotally-mounted, plastic coated, permanent magnet. The ball rolls down the trough and drops into one of the compass box compartments, numbered from 0 to 35. Compartments 0 and 18 are fixed parallel to the axis of the propeller shaft; the magnet always orients to the North. The ball storage tube has a reservoir at the top, closed by a screw cap. Generally 50 percent of its capacity is filled with balls of one color and the balance filled with differently colored balls. Using balls of two different colors assists in determining the approximate time a major underwater directional current change may take place during the measuring cycle. One can readily ascertain the mean current direction, and its variations, by noting the number and locations of the metal balls in their respective compartments. The meter is 30 cm (12 in.) high and 61 cm (24 in.) long with tail fin attached.

The No. 232WA080 Shallow Water Current Meter, Price Pattern, is made to the specifications of the U.S. Geological Survey. Most of the components are fabricated from brass and nickel-plated for protection and good appearance. This instrument is also made in a pygmy size for use in shallow waters or restricted areas.

PRICE:

Prices range from around $275 for a Price meter to $520 for a magnetic contact current meter.

COMMENTS:

The use of current meters was thoroughly covered in Section VI and will not be commented on here.

MANUFACTURER: HINDE ENGINEERING COMPANY OF CALIFORNIA
P.O. BOX 56
SARATOGA, CALIFORNIA 95070
TELEPHONE (408) 378-4112

PRODUCT LINE: PALMER-BOWLUS FLUMES

DESCRIPTION:

The Hinde Engineering Company manufactures "Accura-Flow" insert flumes, which are generally of the Palmer-Bowlus type. These flumes are adaptable to many unpressurized flow measuring applications, including sewage and industrial wastes in open channels or in certain cases, pipelines. Some can also be installed on a temporary basis to verify flow trends. Some of its most important characteristics are reasonable measurement accuracy, low energy loss, minimum restriction to flow, and ease of installation in existing conduits, operation, and maintenance.

The flume is installed in either a "U" channel or circular conduit section with the flume set level at the proper location such that flow through the flume will be laminar, with a slight "ponding" effect just ahead of the flume. If it is desired to measure low flows in a large channel or conduit, this may be accomplished by setting the Palmer Bowlus flume in a channel liner. This arrangement permits accurate measurements where the system flow will gradually increase over a long period of time. Initially, with a small flow rate, the proper size of flume is selected and set in a liner of correct size. Then, as the flow range increases up to the maximum design of the particular size of Palmer Bowlus flume, the next appropriate size is selected and installed. This series of flume modifications permit proper flow measurement up to the design limit of the channel or conduit. Any abnormal flows such as storm water will overtop the flume insert and liner without detrimental effect.

Either on-site or remote registering secondary devices may be used with these flumes to give permanent records of flow rates and totalized volume. Stilling wells, scow floats, and bubbler systems have been successfully used when employing on-site recorders.

The basic Accura-Flow flume (without modifications) is constructed of stainless steel and is a one-piece integral unit. Some examples of the various configurations and applications of this flume are as follows:

- A typical manhole installation (Figure A).
- A flat-bottom flume for measurement in an open trapezoidal channel (Figure B).

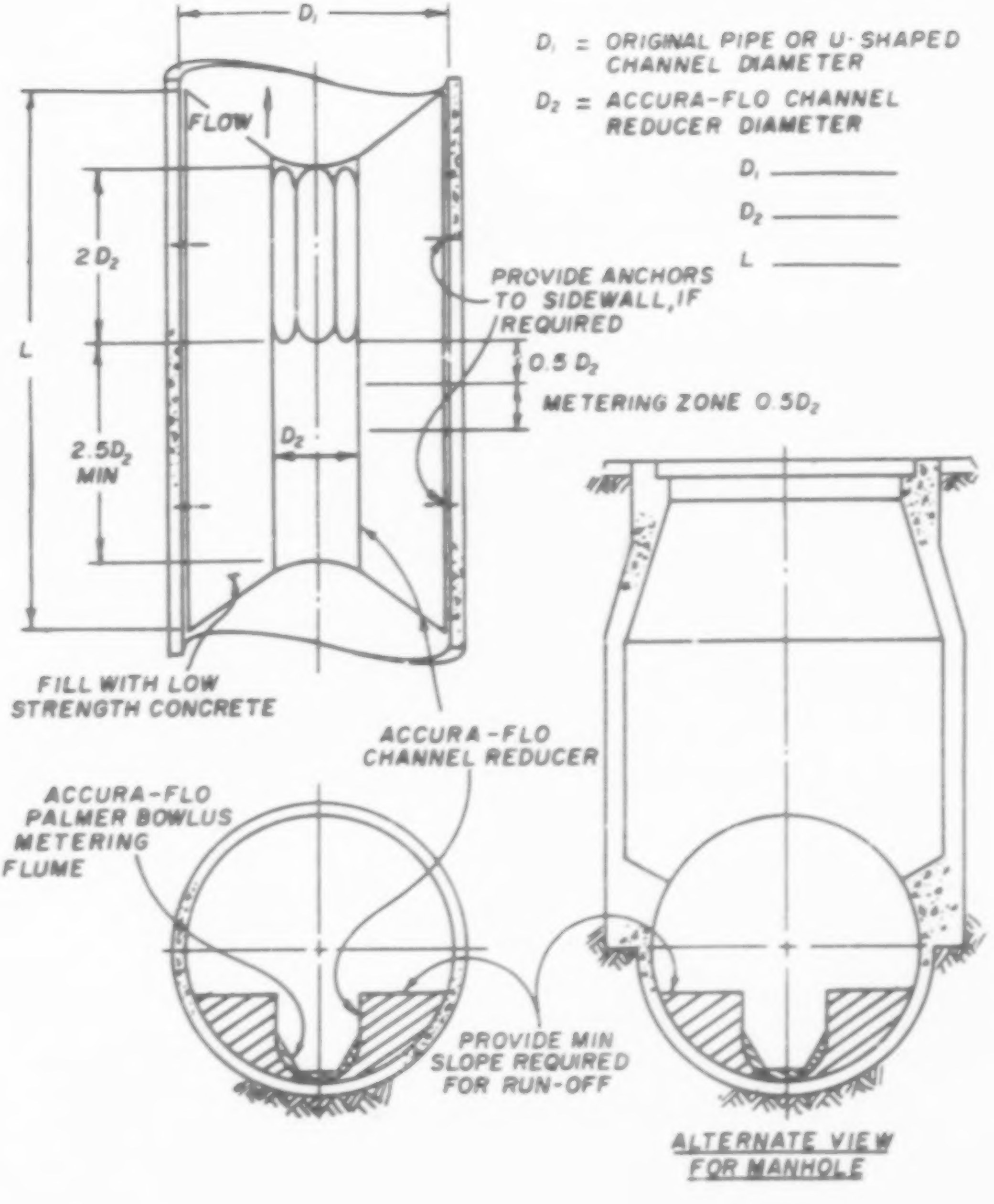

D₁
D₁ = ORIGINAL PIPE OR U-SHAPED CHANNEL DIAMETER
D₂ = ACCURA-FLO CHANNEL REDUCER DIAMETER
D₁ ______
D₂ ______
L ______
FLOW
2 D₂
L
2.5D₂ MIN
D₂
PROVIDE ANCHORS TO SIDEWALL, IF REQUIRED
0.5 D₂
METERING ZONE 0.5D₂
FILL WITH LOW STRENGTH CONCRETE
ACCURA-FLO CHANNEL REDUCER
ACCURA-FLO PALMER BOWLUS METERING FLUME
PROVIDE MIN SLOPE REQUIRED FOR RUN-OFF
ALTERNATE VIEW FOR MANHOLE

Figure A

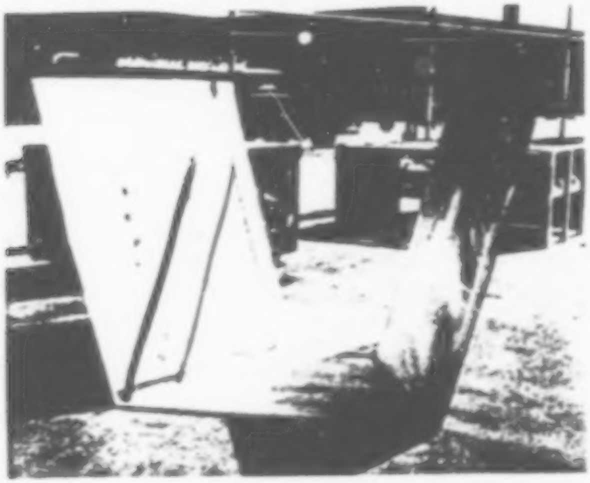


Figure B

Figure C

Figure D

- A flume built into a channel liner fitted with end plate adaptors. This design is intended for use in measuring low flows in an existing channel (Figure C).

- A dual channel assembly, each having a flume of different capacity. The two channels measure seasonal flows on a selective basis (Figure D).

SPECIFICATIONS:

Accuracy:	Comparable to that of Parshall or other types of venturi flumes. Experiments have indicated that, within the normal range of flows (from less than 10% to 90% of pipe capacity), the errors are less than 3%.
Submergence	Less than 0.85 D (pipe diameter or channel width).

Maximum Recommended Slopes and
Maximum Discharge Capacities:

Diameter		Max. Slope	Max. Flow Capacity	
cm	in.	%	ℓ/s	cfs
15.2	6	2.2	9.9	0.35
20.3	8	2.0	19.8	0.70
25.4	10	1.8	35.4	1.25
30.5	12	1.6	55.2	1.95
38.1	15	1.5	96.1	3.40
45.7	18	1.4	151	5.35
53.3	21	1.4	219	7.75
60.0	24	1.3	338	11.95
68.8	27	1.3	416	14.70

MANUFACTURER: HOWELL INSTRUMENTS
3479 WEST VICKERY BLVD.
FORT WORTH, TEXAS 76107
TELEPHONE (817) 336-7411

PRODUCT LINE: SOLID STATE DIGITAL INDICATORS, COUNTERS, TOTALIZERS, RECORDERS, ETC.

DESCRIPTION:

Howell Instruments manufactures a number of precision instruments that might be used as secondary devices in a total flow measuring system.

H600 Digital Indicator - The H600 Digital Indicator is a compact, accurate, and reliable instrument that displays outputs in engineering units from flow meters (square root), frequency transducers, linear signal sources, or signal transmitters (10-50 ma, 1-5 volts, etc.). The display, which uses 0.65-inch characters, includes four digits of data, an out-of-range caption, and an engineering units identification caption. This panel-mounted instrument has a low power requirement, over 120,000 hours MTBF (does not include readout lamps), and low calibration drift. Options include BCD output, analog output, 12- or 28-volt DC power, alarm limit and an alternate case.

H2300 Portable Digital Indicator - The H2300-1 Portable Indicator uses a rechargeable power pack with the H600 Digital Indicator to provide a completely self-contained instrument. The H2300 can be operated as a bench-type instrument from the AC power line even when the power pack has been completely discharged. In addition, the H2300 can be charged indefinitely without harming the power pack.

Multipoint Digital Indicator - The Multipoint Digital Indicator is an enclosed, portable unit that accepts up to 12 two-wire inputs using Howell's H600 Digital Indicator. The indicator uses either pushbutton or toggle switches to select a single input. Switches are identified either by an engraved number on the pushbutton or switch identification cards. Options include 12- or 28-volt DC power and adjustable alarm limits.

H603B Totalizer and H603E Batch Counter - Adjustable scaling (meter factor) is featured in this new series of totalizers and batch counters. Both the totalizers and batch counters count from switch closures, pulses, AC inputs, and voltage transitions; they also include adjustable scaling for a direct engineering unit readout. Plug-in components permit field modification to change the type of input accepted. The totalizer and counter accept input levels as low as 10 millivolts rms and frequencies up to 50 KHz. A seven-segment, half-inch high, gas discharge module provides the display. The H603B and H603C (only difference is in case) totalizers include a six-digit display with movable decimal point. The H603D and H603E batch counters (only difference is in case) have a five- or six-digit display with movable decimal point and include thumb-wheel switches that present the desired batch count. When the displayed number reaches this preset count, a lamp and relay both operate.

The totalizers and batch counters include as standard equipment a counter reset button and a "run" lamp that lights during a counting operation. The totalizers and counters can also be started and stopped by a remote switch closure or TTL signal having a minimum duration of 50 msec. The meter factor is set using binary rocker arm switches. These switches divide the input by any whole number from 1 through 4095 before display. Options are available to expand the division feature (through 65,535) to double the readout to count both positive and negative voltage transitions, and to multiply the input by 1.0000 to 1.9999 which, when combined with the divider switches, can adjust the input to read out input/display ratios that are not whole numbers.

The H603B totalizer and H603D batch counter are housed in a panel-mounted case that permits the chassis to slide out the front of the case for removal or adjustment of meter-factor switches. No tools are necessary. The H603C totalizer and H603E batch counter are also housed in a panel mounted case; however, their chassis are not mounted on slides. The front bezel snaps on, covering the chassis mounting screws. Top and bottom covers are removable to obtain access to all components. A separate temperature compensator module, compatible with the totalizers and batch counters, is available to compensate for specific gravity changes in flow measuring applications.

H490 Digital Data System - The H490 Digital Data System is a flexible, compact system that measures inputs from signal conditioners or transmitters, and other linear sources. Data are displayed and printed directly in engineering units. The H490 System can operate from two different sensors and can monitor from 10 to 100 points. Scanning modes include (a) continuous monitoring of either one or all points and (b) manually initiated scanning of all points one time. Points can be omitted from the scanning sequence in groups of ten. A timed-start feature permits unattended system operation by automatically initiating a print sequence at every 10, 20, 30, or 60 minute interval. The standard printout consists of a six-digit time group, two digits of point identification, and four or five digits of data together with appropriate range identification. As an optional feature, up to two limits are available. They can be programmed as high or low and adjusted to operate an alarm relay at any point in the readout range.

H4200 Digital Data System - The H4200 Digital Data System is a fast-reading, high-input capacity system that measures signals from signal conditioners or transmitters, and other linear sources. Data are displayed and printed directly in engineering units. Catalog modules are combined in the H4200 to provide (a) four recording options, (b) speeds of up to 20 points per second, (c) up to 1000 inputs, (d) either one or two individual limits per point, (e) up to four different ranges, and (f) point omission either singly or in groups of 10. The H4200 system generates output data that are recorded on a line printer, an electric typewriter, or a teletype unit. Two types of out-of-limit detection and alarm devices are available. One type provides one limit, either high or low, for each point. The other type offers two limits - high and low, high and higher, or low and lower - for each point. Limits are digital, can be either positive or negative, and are adjustable throughout the range of the system. Scanning modes include (a) continuous monitoring of one point, (b) continuous scanning of all points, or (c) manually or automatically initiated single scan of all points. Any of these modes can be initiated either locally or remotely by an external switch closure. Points can also be manually selected and printed one point at a time.

H4500 Digital Data System - The H4500 Digital Data System uses a digital processor (computer) to control the system. Ability to readily produce a custom software package has enabled Howell to design standard hardware that can be tailored to a great variety of customer needs. Operational modes, types of signals measured, the display and printout format, and any computational and correctional operations performed in the computer can be designed to customer requirements.

The H4500 System measures and records data in applications where a number of points and/or parameters must be accurately recorded in engineering units. This system is ideally suited to applications involving measurement of nonlinear signals or measurements requiring corrections and computations dependent on other parameters. The H4500 can measure inputs directly from all industrial type sensors including speed and flow types (frequency), transducers, strain gages (pressure, torque, load, displacement, etc.), and other transducers having a voltage, resistance, or frequency output. The H4500 can also accept signals from signal conditioning transmitters (10-50 ma, 4-20 ma, 1-5V, etc.) or provide state indications of contact closures. A typical H4500 System consists of a freestanding equipment cabinet, which includes a digital processor; a teletype terminal; and one or more display modules. The system can accommodate up to 1024 inputs, scan up to 50 points per second, and detect out-of-limit points. The remote digital display reads out both measured and computed data. While the Teletype is not the only input-output device available with the H4500 System, it offers a satisfactory compromise between versatility and economy in most applications. The teletype terminals's function is two-fold. First, it operates as a printer to record data in any of the various operational modes. Second, keyboard commands to the digital processor initiate the operational modes, omit points from scanning, change limits, store point messages, and even change scaling and zero offset of points on an individual basis.

Optional features include alarm limits, printed English language messages to simplify point identification, computed and corrected values (square roots, logs, differential measurements, etc.) based on input signal measurements, and remote readout(s). Other options include a CRT display with or without an input keyboard, a high speed line printer, separate alarm message printer, analog outputs for trend recording, timed start for unattended installations, computer interface, and magnetic tape recording equipment.

MANUFACTURER: INTEROCEAN SYSTEMS, INC.
3510 KURTZ STREET
SAN DIEGO, CALIFORNIA 92110
TELEPHONE (714) 299-4500

PRODUCT LINE: CURRENT METERS, WAVE AND TIDE GAGES

DESCRIPTION:

As its name implies, InterOcean Systems offers a wide line of sensors and instrumentation initially designed for oceanographic applications. Several of the products they market could find use in the wastewater area, however. Their current meters include the Ekman-Merz, ducted impeller, Savonious rotor, and electromagnetic types. These meters are available as self contained units with analog or digital self-recording or as remote units with real-time readout. Of the current meters just mentioned, only the electromagnetic self-recording Model 195 will be described.

Model 195 Current Meter - The Model 195 Current Meter incorporates the inherent advantages of a solid-state, no-moving-parts sensor with many optional sensors for environmental monitoring as well as automated instrument recovery. A unique data preprocessing circuit and flexible data formatting are combined with a computer-compatible digital cassette data recording system.

The entire instrument may be installed below the water surface on any structure or it may be implanted on the bottom. Being out of sight drastically reduces its vulnerability to vandalism and accidental mishaps. The current speed, direction, time and optional parameters may be recorded for periods up to 90 days (or one year, optional). At the end of the monitoring period, when the operator replaces the digital tape cassette and batteries and cleans the sensor head, the instrument is ready to be deployed again. The data recorded on the cassette are ready for transcription or direct computer data processing.

The current sensor consists of an electromagnet and two electrodes encapsulated in a rugged, waterproof anti-fouling neoprene assembly. The electromagnet produces a magnetic field. When the water passes through the magnetic field, a potential gradient is produced which is sensed by the electrodes. The voltage representing the magnitude of the water current is fed into the solid state signal processing electronics, digitized, and recorded on the internal digital cassette magnetic tape recorder.

STG/100 Wave and Tide Gages - These gages are used to monitor waves and tides over wide ranges with extremely high precision. The instrument can be used to sense rapid or gradual level fluctuations in lakes, rivers, estuaries, harbors and ocean coastal zones. The basic instrument contains a sensitive, temperature-compensated, multi-turn Bourdon tube pressure element. A patented optical system senses the pressure signal, eliminates hysteresis and provides a wide dynamic operating range with no sacrifice in high precision. Both remote and self-contained models are available. The remote model has a cable connected to a remote power supply, data display, and recording station. The self-contained recording model is available with either a miniature strip chart recorder or a digital magnetic tape cassette. The response time of the instrument is adjustable by using one of a variety of filters available. This feature permits optimum use of the basic instrument for the study of phenomena ranging from short period wind waves through tides.

A light beam focused through a unique grid system is used to sense very small changes in rotation of the freely suspended Bourdon tube. An electronic servo network nulls the light beam signal to provide a highly accurate and linear output over a single small scale. The grid system also provides for multiple scale nulls so the dynamic range of the instrument is greatly extended without affecting the accuracy. The instrument can be attached to existing or specially provided structures, or lowered directly to the bottom. Since the instrument functions as a multiple null detector, it is ready for use without any adjustments independent of the water depth into which it has been placed. Accuracy is independent of water depth.

SPECIFICATIONS:

Model 195 Current Meter

Sensor

Type:	Electromagnetic
Range:	0.03 to 3 m/s (0.08 to 10 fps)
Accuracy:	±2% Full Scale
Resolution:	0.03 m/s (0.08 fps)

Compass

Type:	Permanent Magnet
Range:	0 to 360°
Precision:	±5°

Recorder

Type:	Digital, Cassette
Capacity:	2.7×10^6 Bits

Precision:	12 Bit Words
Record:	Identification Word-Time-Speed-Direction-Options
Format:	Programmable; Instantaneous, High/Low/Mean, High Density

Clock

Type:	Digital, Solid State
Accuracy:	±0.01%

Dimensions

Sensor:	2.5 cm (1 in.) OD x 18.5 cm (7.25 in.)L
Pressure Case:	16.5 cm (6.5 in.) OD x 84 cm (33 in.) L
Weight:	10 kg (22 lbs) in air

Model STG/100 Wave and Tide Gage

Range:	30m (98 ft)
Precision:	±3 mm (0.01 ft)
Wave Filter:	None for short period waves; as required for longer period waves.
Clock:	Bulova Accutron with hourly event marker.
Data Interval:	Continuous, once per min., or others optional.
Operating Time:	20 days minimum on self contained tide models or up to one year optional.
Operating Depth:	200 meters maximum; others available.
Power:	Internal mercury batteries; optional rechargeable batteries or external supply.
Pressure Case:	Hard Anodized Aluminum 20 cm (8 in.) diameter by 38 cm (15 in.) long.

PRICES: Not available at time of writing.

COMMENTS:

The electromagnetic current meter may find some use as a portable device for survey work. The rather novel wave gage is essentially a head sensing device, and would appear promising as a secondary element for use with head-area type primary devices for certain specialized applications.

MANUFACTURER: J-TEC ASSOCIATES, INC.
317 7TH AVENUE
CEDAR RAPIDS, IOWA 52401
TELEPHONE (319) 366-7511

PRODUCT LINE: LIQUID FLOWMETERS, CURRENT METERS

DESCRIPTION:

J-TEC Associates Inc., a recently established firm (1968), has developed a sonic vortex flow measurement technique which they believe "will advance the state-of-the-art in the water and wastewater fields". The company has patented a technique for the measurement of the vortex or eddy shedding frequency behind an obstruction or strut in a fluid flow stream by using an ultrasonic beam. The company's liquid flowmeters, similar to their VF-500 gas flowmeters, are designed to measure liquid flow in full pipes; their Model CM-1106B current meter is suitable for the measurement of open channel fluid flows.

In the J-TEC ultrasonic vortex-sensing device, an ultrasonic beam is passed through the vortex path ard, in effect, counts the number formed per second to determine velocity. An ultrasonic signal is received from a transducer across the flow path and is modulated both in amplitude and phase at the vortex shedding velocity. The signal is processed so that output pulses are a direct, linear measure of flow velocity.

Liquid Flowmeters - The detected modulation frequency is used as the primary output of the flowmeter. This frequency can be counted for a direct digital display of flow rate or applied to a frequency converter for a voltage or current output. Although this flowmeter uses the same technique as the VF-500 series gas flowmeters, usable ranges for this meter will be (as stated by J-TEC) approximately ten times lower than listed for each gaseous model, respectively. Flowmeters utilizing the J-TEC technique have been used over a strut Reynolds number range of 100 to 36,000; in terms of pipe Reynolds number, a value of 900 is necessary to achieve sufficiently turbulent flow to support vortex formation. There are no moving parts associated with this device. Liquid flowmeters are available only on a special order basis.

Current Meter - The CM-1106B is a true fluid speed (current) indicator for use in open channel flows. As in the case of the liquid flowmeter, this device uses the J-TEC ultrasonic technique for flow speed measurement. An electronic processor provides the user with a choice of outputs - pulse frequency proportional to fluid velocity or analog voltage corresponding to fluid velocity.

SPECIFICATIONS:

Current Meter

Accuracy:	±1%
Speed Range:	0.1-5 m/s (0.3-15 fps) (standard)
Power:	12 VDC, 50 mA
Size:	12.7 cm (5 in.) High X 5.08 cm (2in.) Diameter

PRICE: Flowmeters - Available on special order basis only

Current Meter (CM-1106 Serires) - $1,090.00 up (depending upon model, display, and accessories used)

COMMENTS:

As long as the Strouhal number remains constant, the number of vortices generated per unit time is directly proportional to the flow velocity of the medium involved. Any change in the diameter of the strut, e.g., due to build-up or debris entanglement, will change the sensor's calibration constant and its accuracy. Therefore, unattended operation in wastewater flows does not appear attractive.

MANUFACTURER: KAHL SCIENTIFIC INSTRUMENT CORPORATION
P. O. BOX 1166
EL CAJON, CALIFORNIA 92022
TELEPHONE: (714) 444-2158

PRODUCT LINE: CURRENT METERS, ACCESSORIES, FLOATS, AND FLUORESCENT DYES

DESCRIPTION:

"KAHLSICO" markets a wide range of hydrological and oceanographic instrumentation, including the products of GM Manufacturing and Instrument Corporation discussed earlier. A few of their offerings will be described.

Integrating Remote Water Current Motor (No. 231WA550) - This meter uses a Savonius type rotor for measurement of liquid flows. The rotor uses two balanced Savonius sections, one above the other and displaced 90 degrees around their circumference to assure actuation omnidirectionally about the horizontal plane of the sensor. The rotor has 14 magnets aligned in its base to inductively activate (14 times per revolution) the electrical switch in the sensor's housing. The opening and closing of the electrical circuits, which is directly proportional to the speed of the water current, is monitored by a pulse-shaping network, the 0 to 20 mA output of which goes into a counter, fast integrator, and finally to the indicator meter (and, optionally, a recorder or other readout). The response time of the circuit is practically instantaneous; it readily follows any changes in the turning rate of the sensor. The system does not saturate and is said to be able to discriminate and count the actuations of the sensor, even when it is exposed to a fast current of 3 m/s (6 kn).

Fluorescent Dyes - Fluorescent colors are available in either red or yellow/green. Unless otherwise specified, red color is supplied on orders. Yellow/green provides a stronger color when testing silty waters as the grains of silt absorb the fluorescent red. When used in a closed system such as a sewer conduit, the dye will last for several days. Depending upon the clarity of the water, 2 to 5 tablets will provide a visibility of 1 part per million. The tablets are 2.9 centimeters (3/4 inch) in diameter and packed 100 per plastic envelope. Maximum absorbance is 550 mμ. Dye cubes are generally used for oceanographic studies or where large masses have to be traced. Kahl also markets an in-situ opto-electronic fluorometer (VARIOSENS).

Current Drifters and Drogues - KAHLSICO offers a number of current drifters and drogues in three basic types. The surface drifter is essentially two sealed, heavy-gauge, clear plastic envelopes sized 7.5 x 12.5 cm (3x5 in.). A drift envelope is a similar waterproof envelope measuring 15 x 23 cm (6x9 in.) with a 34 grams (1.2 oz) weight at the bottom to provide vertical floatation. Since only a small portion of the envelope is exposed to the wind, the major drift force is the surface water current.

The ball-shaped Tri-Planar Surface Drogue is molded from brightly-colored, buoyant, polyethylene plastic, with a 53 cm (21 in.) long flexible, weighted stem. This 15 cm (6 in.) diameter drifter has two vertical discs, 180 degrees apart, bisected by a horizontal disc at their center. The flexible stem has a tubular weight crimped at its lower end which keeps the drogue floating just below the water surface, to eliminate the effect of wind. The horizontal disc prevents undue motion in the vertical direction while the vertical discs have the effect of presenting the same surface area to water currents from any side.

The Surface Current Drogue has a large floatation cork at the top of the 53 cm (21 in.) long, flexible stem and a 20 cm (8 in.) diameter saucer at the weighted bottom end.

Also offered is the Woodhead sea-bed drifter which has been in successful use for over two decades for surveying bottom currents. The brightly colored, 20 cm (8 in.) diameter, plastic dish has a series of holes to facilitate vertical descent to the sea-bed. To assure rapid passage through deep waters, several drifters are usually attached to a salt block which dissolves in from 20 to 30 minutes to release the drifters which are then jogged along the bottom by the water current.

SPECIFICATIONS:

No. 231WA550 Integrating Remote Water Current Meter

Speed Range:	0.05 to 3 m/sec. (0.1 to 6 knots)
Meter Scale:	0 to 6 knots in 0.1 knot and 0 to 10 ft/sec in 0.2 ft/sec (m/sec scales, as well as expanded scale ranges of 0 to 1 knot and 0 to 6 knots, are available on special order).
Threshold and Sensitivity:	0.05 m/sec; 0.1 knot, 0.17 ft/sec
Distance Constant:	0.74 revolution = 30.48 cm (1 ft) of linear water movement.
Recorder Output (Optional):	A recorder connector provides 0 to 20 mA maximum output to operate a 250 ohm minimum internal impedance circuit for a recorder, data logger, etc. (Other outputs available on special order.)

Optional External Power Supply:	12 to 30 VDC, 6 mA consumption at 18 VDC, available on special order.	
Built-in Power Supply:	Four Alkaline Batteries, each 4.5V, connected in series (18V total).	
Battery Life:	Approximately 150 hours.	
Dimensions:	Sensor	Control Box
	20x20x26 cm (8x8x10 in.)	21x16x14 cm (8.3x6.5x5.5 in.)
Weight:	3 kg (6 lbs)	2 kg (4 lbs, with batteries)

PRICES:

No. 231WA550 - Integrating Remote Water
Current Meter - $763.00

COMMENTS:

Items offered by Kahl were discussed in Section VI and will not be commented on further.

MANUFACTURER: F. B. LEOPOLD COMPANY
DIVISION OF SYBRON CORPORATION
227 S. DIVISION ST.
ZELIENOPLE, PENNSYLVANIA 16063
TELEPHONE (412) 452-6300

PRODUCT LINE:

PRIMARY DEVICES - FLUMES, OPEN FLOW NOZZLES
SECONDARY DEVICES - TRANSMITTERS, RECEIVERS

DESCRIPTION:

Flumes - Leopold-Lagco fiberglass flumes are Palmer-Bowlus type primary measuring devices with a rectangular cross-section. They are molded of LEO-LITE, a patented plastic resin material reinforced with glass fibers. Installation is directly in the sewer line, normally at a standard straight-through manhole. Flume construction is claimed to be sturdy enough to permit direct use as a concrete form in permanent installations, and do not require maintenance.

Leopold-Lagco flumes are available in three standard types - fixed, insert, and cutback. The fixed type is generally used in new constructions where the flume is installed in place of an equivalent length of straight pipe. The insert type is designed for use in those installations where the flume can be inserted into an existing half section of sewer pipe; it is particularly well suited for flow "spot checks" where a more permanent installation is not required. A modification of the insert model, the cutback, is used where space is critical. Inserting the "cutback" into a manhole or vault outlet provides more room upstream for metering, sampling, or other devices. Design capabilities of this flume include the following:

- Demonstrated measurement of low flows in near-zero range.
- Can be equipped with a pointer gage mounted on it for intermittent flow readings.
- Can be used with all of the better-known float-actuated meters, including those with telemetering capabilities.
- Some installations have successfully incorporated air bubbler systems. However, provisions have to be made to eliminate the aspirating effect caused by flow past the bubbler orifice.

F. B. Leopold also manufactures a complete line of LEO-LITE Parshall flumes and Parshall flume liners in throat widths from 7.6 cm (3 in.) to 2.4m (8 ft). Complete LEO-LITE Parshall flumes have stiffeners and spacers for immediate field installation. Leopold also offers cast iron parabolic flumes (open flow nozzles) in a variety of sizes.

Float in Flume Transmitter - Leopold float-in-flume transmitters are designed to continuously indicate the flow of sediment-laden liquids as they pass through Lagco or Parshall flumes or parabolic open flow nozzles under gravity conditions. Liquid flow is indicated by the direct sensing of the level of the liquids within the flume or nozzle; flow data are transmitted either electrically or pneumatically to a remotely located flowmeter.

The transmitter is either mounted directly on the wall of the Parshall flume or on the parabolic nozzle itself. A corrosion-resistant "ski" type sensor (float) rides directly on the surface of the liquid flow stream; it does not cause disturbance on the surface of the liquid or excessive oscillation in recording instrument. As the surface of the liquid rises or falls, depending upon the flow through the flume or nozzle, the sensor changes its position accordingly. This movement produces proportional angular movement of the sensor arm and shaft on which it is supported.

For electric transmissions, the shaft arm angular movement is transferred to a stylus riding over a characterized cam which is corrected for non-linearity and furnishes a linear signal proportional to flow which is transmitted every 15 seconds, with a pulse duration varying from a fraction of a second to approximately 12 seconds. Three seconds of each 15-second period are required for the receiver to reset for the reception of the next signal.

For pneumatic operation, the shaft arm angular movement is transferred to a shaft carrying a cam characterized to the head quantity relationship of the flume. A pneumatic tracing device senses the profile of this cam and transmits a linear, 3 to 15 psig pneumatic signal through an amplifying relay to the receiver.

Advantages of this device include the following:

- Reduces installation space
- Faster responses to flow changes
- Reduces material costs - eliminates stilling wells, connecting piping and fittings, large float and cable, back purge system, etc.

Recorders - The Leopold Type "K" electric receiver/integrator (totalizer) is adaptable for installation at locations remote from the transmitter and will operate over private two or three wire systems or a pair of leased telephone wires. Designed to operate with an accompanying time impulse transmitter, this receiver can be applied to the measurement and control of flow, level, pressure, and temperature. The unit features a 30-centimeter (12-inch), 24-hour chart and nonremovable chart hub; indicator, which operates over standard scale - 0 to 100 percent of chart range; and a continuous reading, seven-digit type totalizer.

SPECIFICATIONS:

Leopold-Lagco Flumes

Accuracy:	up to ±2%
Flume Sizes:	15.2 to 183 cm (6 to 72 in.)
Flow Capacity:	7.25 to 3,313 ℓ/s (0.25 to 118 cfs)

PRICES:

Leopold-Lagco flume prices range from around $300 to over $3,000 depending upon material (i.e., LEO-LITE 87 or 82) and additional features such as integral stilling well, scale, etc.

COMMENTS:

These products have been discussed in Section VI and will not be commented upon here.

MANUFACTURER: LEUPOLD & STEVENS, INC.
P.O. BOX 688
600 N.W. MEADO[illegible] DRIVE
BEAVERTON, OREGON 97005
TELEPHONE (503) 646-9171

PRODUCT LINE: FLOWMETERS, RECORDERS, GAGES

DESCRIPTION:

Leupold & Stevens is an old-line company whose products probably need little introduction. It is to be noted that they have recently discontinued their Model 561R, a float-in-flow transmitter and remote registering total flowmeter, and Model G161R, a bubbler-type remote registering total flowmeter. This company currently offers, in addition to staff gages, devices for measuring flow rates and totalizing volume in open channels for industrial wastes and municipal sewage. These include the Stevens Model 61 series total flowmeters and the Type F recorder.

Flowmeters - Stevens total flowmeters are designed for on-site measuring of open channel flows. They are available in either English or metric units, and can be used with any type and size of weir or flume. With appropriate cam, gears, and scale, flows up to approximately 800,000,000 liters (several hundred million gallons) per day can be measured through large sizes of Parshall and other types of flumes. Conversely, a full scale range as small as 0-53,200 ℓpd (0-14,000 gpd) through a 22-1/2-degree V-notch weir is available. An AC synchronous motor drive powers a 7-digit totalizer (for indicating volume) and chart drive. For applications where commercial power is not available, an 8-day, spring-drive clock can be obtained. Figure A shows a typical manhole flow measuring installation.

The Model 61M provides visual indication only. The indicator plate is graduated to show instantaneous flow rate as noted by the indicator pointer. A red clip on the indicator plate is positioned by the pointer to indicate peak flow.

The Model 61R uses a strip chart to provide a permanent record of flow. A standard 15m by 10.1 cm (50 ft by 4 in.) strip chart is printed on humidity-resistant tracing paper. Curvilinear time graduations compensate for arc swing of the marking pen, with six minor divisions between major divisions. Charts are time overprinted every 2, 3, 6 or 12 hours, depending upon time scale. The chart has uniform divisions for flow, consisting of 7 major and 5 minor divisions.

Available time scales are 8.5, 12.7, 25.4, or 50.8 cm (3-1/3, 5, 10 or 20 in.) of chart travel per day giving 180, 120, 60, or 30 days of continuous records, respectively.

Up to 180 days of unattended operation is claimed for these devices.

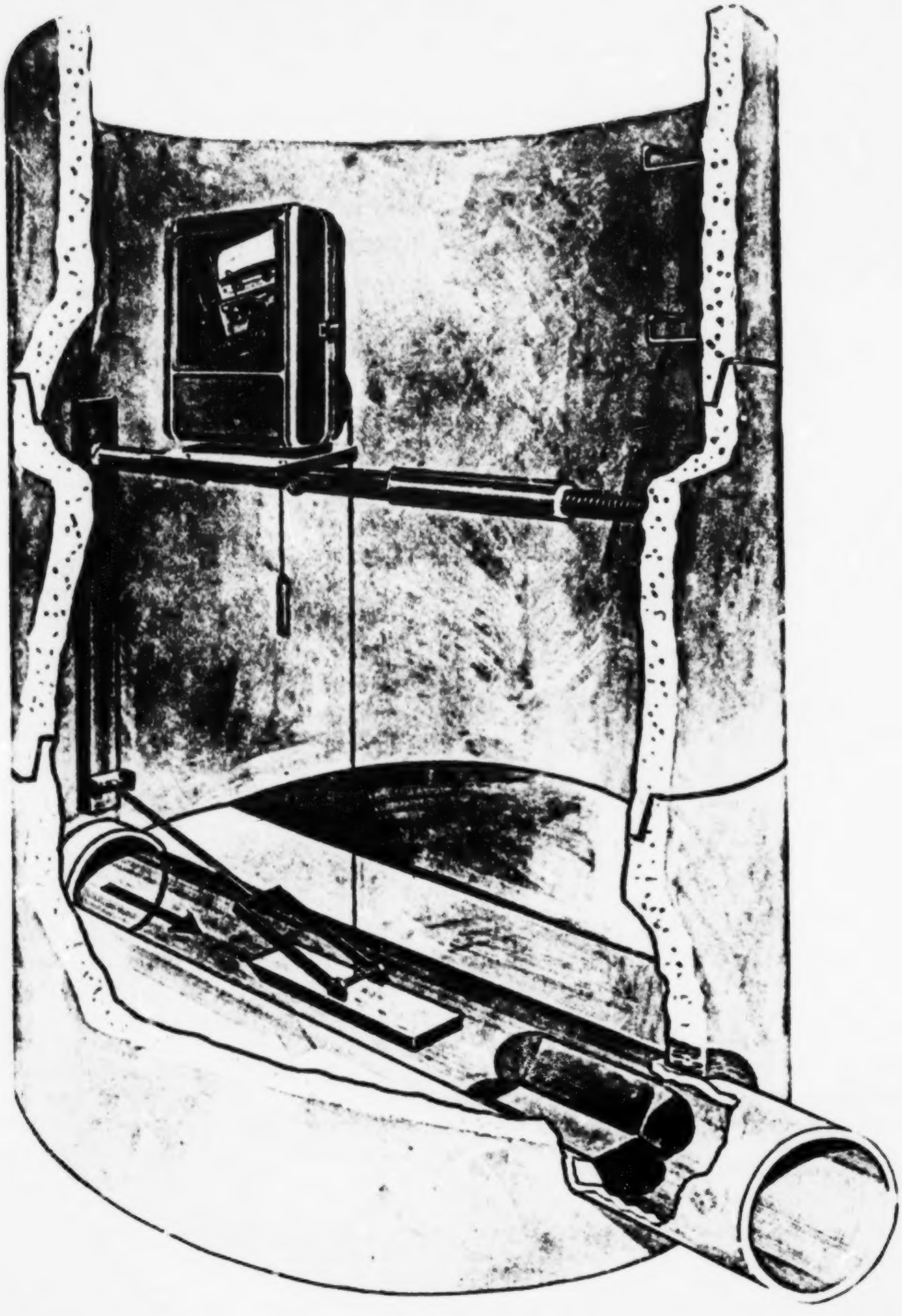
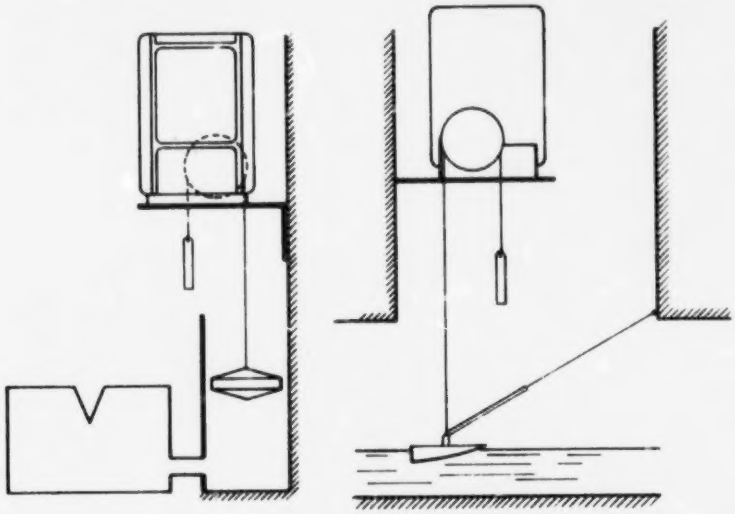


Figure A

It is recommended by the manufacturer that a stilling well installation and standard cylindrical float be used whenever possible in order to obtain better accuracy and chart record (a properly designed stilling well dampens out surface undulations and wave action). For some applications, however, a scow float installation can be used to good advantage. Figure B shows two such installations.



Stilling Well Installation

Scow Float Installation

Figure B

Recorder - It has been claimed that the Stevens Type F recorder is the lowest price instrument of its kind for recording open-channel flows through Parshall flumes or 90-degree V-notch weirs. In operation, a horizontally supported chart drum is turned by a float (resting on the water being measured) proportional to changes in water level. A pulley drive mechanism, controlled by an 8-day clock, moves the pen across the chart at a constant speed. The combined movement of the drum and pen produces a graphic record of changing water levels.

SPECIFICATIONS:

Operating features and characteristics are discussed in the preceding equipment descriptions.

PRICE:

Standard prices were not available at the time of this writing.

COMMENTS:

Leupold & Stevens equipment has proven to be rugged and reliable in many types of wastewater measurements. They have also provided custom application telemetering equipment ("telemark") for more complex systems use.

MANUFACTURER: MANNING ENVIRONMENTAL CORP.
120 DU BOIS STREET
P.O. BOX 1356
SANTA CRUZ, CALIFORNIA 95061
TELEPHONE (408) 427-0230

PRODUCT LINE: LIQUID LEVEL MONITOR

DESCRIPTION

The Manning F-3000 Dipper flowmeter series technique is basically a method of detecting liquid level in open channel flow by sensing the surface of the water. The control electronics are included in a modular package, which is mounted, for example, on a portable bracket at the top of a manhole. A thin, non-corrosive probe is lowered on a wire controlled by a small precision motor. When the metal probe makes contact with the liquid surface, a microampere circuit is made through the conductive liquid to a ground return. This signal reverses the motor, raising the probe slightly above the surface. After 5 seconds, the probe is lowered to the surface again, and again retracts. This "dipping" action continues with the probe just above the surface of the liquid. These changes in cable length are translated to a rotation of a measuring wheel. See the electromechanical schematic in Figure A.

The flowmeter converts the height signal into a flow rate recording, a total flow recording, and sampler switch to provide flow proportional sampling. It can convert from height to flow measurement for many types of pipes, flumes, and weirs. The rotation of the height measuring wheel controls an electronic servo system to change to an output which is proportional to flow. A channel selector allows easy selection of proper channel shapes -- round pipes, weirs, flumes. The flow proportional output (1) positions a pen indicating instantaneous flow rate on a recording chart or (2) provides an indicator showing instantaneous flow rate and (3) rotates a potentiometer which provides an input to the totalizing circuit. This circuit generates a pulse stream proportional to the flow and the accumulated count is shown on a total flow counter on the front panel.

Advantages claimed for the Manning portable flowmeter include:

- Quick installation at street level -- The Dipper Flowmeter allows one man to install this meter at street level in less than 10 minutes.

- Sensor not affected by floating debris -- No floats, scows, tubes, capacitive plates for debris to hang on. No stilling wells to clog. The Dipper sensor never enters the flow.

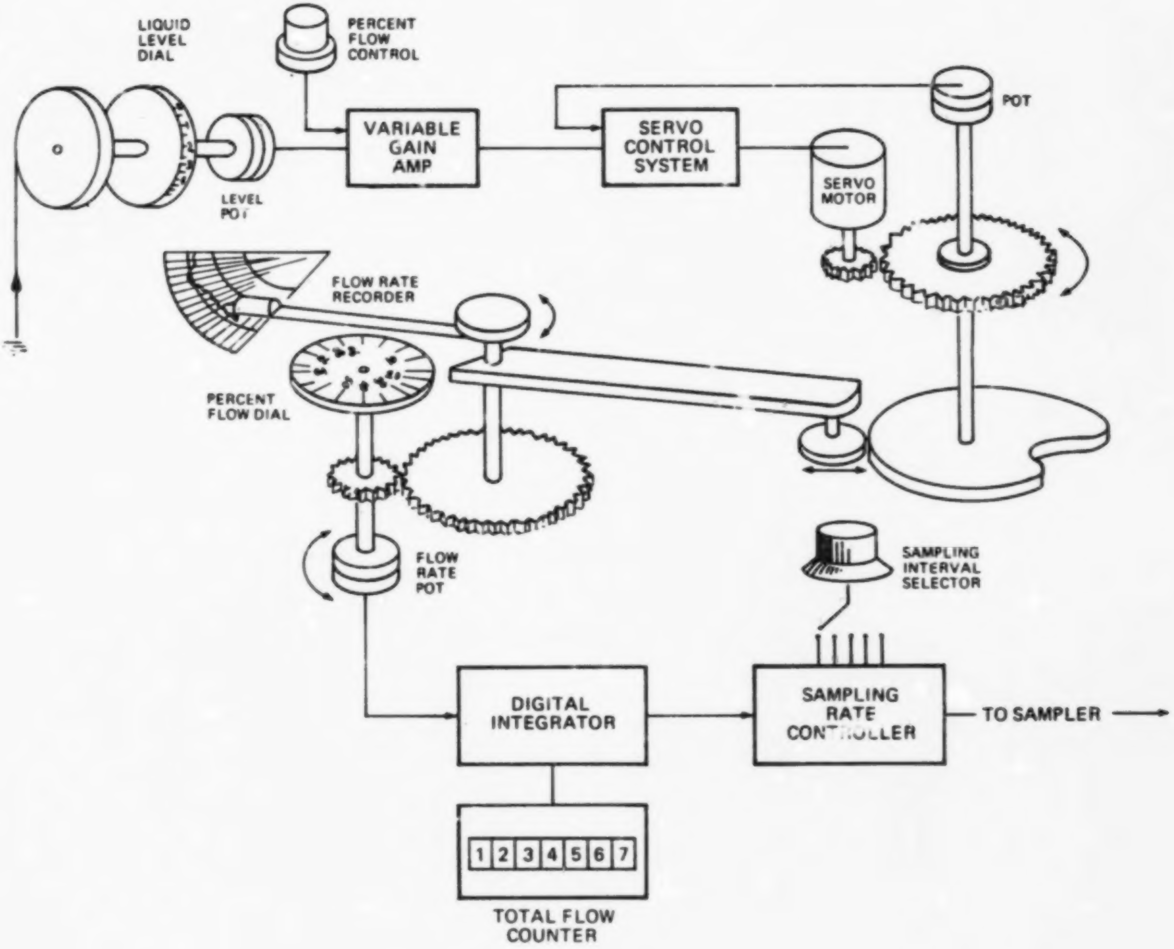

LIQUID LEVEL DIAL
PERCENT FLOW CONTROL
LEVEL POT
VARIABLE GAIN AMP
SERVO CONTROL SYSTEM
POT
SERVO MOTOR
FLOW RATE RECORDER
PERCENT FLOW DIAL
FLOW RATE POT
SAMPLING INTERVAL SELECTOR
DIGITAL INTEGRATOR
SAMPLING RATE CONTROLLER
TO SAMPLER
1 2 3 4 5 6 7
TOTAL FLOW COUNTER

Figure A

- Direct reading accuracy -- Direct mechanical coupling to the surface level gives better than .003m (0.01 ft) level accuracy over the total range. Servo-controlled, electronic conversion provides extremely high accuracy for flow rate and total flow.

- Easy-to-read flow chart -- Switch selectable (7 day or 24 hour) circular chart gives easy to read indication of changes in flow rate with time, peak flow, etc. Operates with a spring driven, 8-day clock drive.

- Digital Total Flow Counter -- A non-volatile counter records total flow over the given time period. Records with digital accuracy.

- Battery Operation -- Operates on small 12-volt rechargeable battery.

SPECIFICATIONS:

Maximum Height of Flow Range:

6-24 in. (F-3024)
12-48 in. (F-3048)
15-60 cm (F-3060)
30-120 cm (F-3120)

Channel Shapes Included (Switch Selectable):

Round pipe
V-Notch Weir
Palmer-Bowlus Flume
Parshall Flume
Leopold Lagco Flume
Cipolletti Weirs
(Others available on special request).

Maximum Total Flow Recording:

Up to 999,999 times maximum flow per minute in channel. (For example: If maximum flow is 1000 gallons per minute -- maximum recording 999,999,000 gallons.)

Size: 23x36x20 cm (9x14x7.75 in.)

Weight: 5.5 kg (12 lbs)

Flow Rate Indication: 0 to 100% in 5% divisions

PRICE: Approximately $1,000 and up, depending upon options.

COMMENTS:

This portable liquid level monitor and flow converter has a lot to recommend it as a secondary device for translating depth into flow rate in many storms or combined sewer applications. The range is less than might be desired for some sites, and collision with surface debris could cause an oscillation of the pendulum-like dipper probe resulting in some inaccuracy until the swinging motion subsides. It also might be possible for the probe to become coated after extended periods of use, which could result in a zero-offset. Otherwise, the unit appears quite promising and merits serious attention as a new technique for measuring liquid levels.

MANUFACTURER: MARTIG BUB-L-AIR
2116 LAKEMOOR DRIVE
OLYMPIA, WASHINGTON 98502
TELEPHONE (206) 943-2390

PRODUCT LINE: PORTABLE LIQUID LEVEL RECORDER

DESCRIPTION:

This unit is a very recently introduced (Spring 1974) device for measuring and recording depths of wastewater flows. It is expressly designed for manhole use. The equipment package for an installation consists of a recorder; compressed air bottle; regulators, connecting hose, and fittings; sensing probes for sewer pipe; and miscellaneous slings and straps for mounting in a manhole. The device measures flow depth only, and the user must apply conversion factors as appropriate for the primary device employed.

SPECIFICATIONS:

The spring-wound recorder has two settings for either 24 hour or 7 day operation and uses 20.3 cm (8 in.) diameter charts graduated from 0 to 30 inches. The pen has a fine tip for use in humid environments and uses three drops of ink for a fill. One and two pen models are available and are housed in a weatherproof case.

The compressed air bottle is lightweight aluminum with a 1,260,000 kgf/sq m (1,800 psi) working pressure. Various sizes are offered for fill lifes from 3 to 8 weeks. The primary regulator is a single stage unit which reduces bottle pressure to about 24,600 kgf/sq m (35 psi). The secondary regulator is used to adjust air flow rates to bubbles per second as visually observed through a mineral oil reservoir. Stainless steel sensing probes are available in standard sizes from 15.2 to 76.2 cm (6 to 30 in.), and other sizes can be supplied on special order.

PRICES:

Complete packages start at $1,149. These packages include a one-pen recorder, three sensing probes, and all equipment necessary for installation and use.

COMMENTS:

These devices are sold direct from the factory only, on a thirty-day, free-trial basis. The manufacturer is pleased that in the nine months that this offer has been in effect, not one unit has been returned, and ninety percent of their customers have placed orders for additional equipment.

MANUFACTURER: MARV TEC, INC.
C/O HARRY H. BARNES
613 EAST BAYVIEW, HILLSMERE
ANNAPOLIS, MARYLAND 21403
TELEPHONE (301) 261-2987

PRODUCT LINE: ACOUSTIC LIQUID LEVEL MEASURING SYSTEM

DESCRIPTION:

The Aquarius Model 2001 or 2002 Liquid Level Measuring System is a very recenlty developed (patent pending) instrumentation system which employs acoustic ranging techniques to measure liquid levels to within 0.03 cm (0.001 ft) over a range of 0 to 30m (0 to 100 ft). Continuous calibration is employed to automatically compensate for ambient changes of temperature, humidity, and pressure of the gaseous medium above the liquid. This technique entails monitoring a coincident return signal from a known distance within the sensor head assembly, mathematical circuitry manipulation, and application of the resultant factor to the signal of interest for determination of the unknown distance.

Advantages of this system are that it has no moving parts, does not contact the liquid being monitored, and reportedly can be used in extreme environmental conditions to monitor corrosive liquids in corrosive atmospheres.

A complete system, shown in Figure A consists of (a) sensor head assembly, (b) stilling well, and (c) remote electronic package and control panel for one or more sensor head assemblies.

The function of the stilling well is to support the sensor head assembly and contain the transmitted and return acoustic signals. It consists of plain pipe of appropriate material, the type of material used being dependent upon the liquid being monitored.

The Model 2001 and Model 2002 are similar in outward appearance, except that the Model 2001 is continuously energized whereas the Model 2002 can be interrogated at specific intervals and will respond within 50 milliseconds, no power being consumed during the quiescent period.

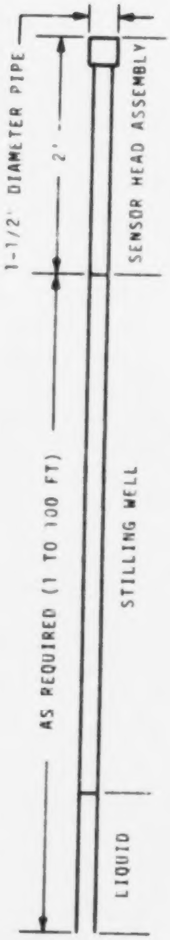


Figure A

SPECIFICATIONS:

Accuracy*:	0.3 cm throughout 30.3m range (0.01 ft throughout 100 ft range) 0.03 cm throughout 3.03m range (0.001 ft throughout 10 ft range)
Power:	Model 2001, 1 amp @ 5 VDC Model 2002, 3 amps @ 5 VDC (only during interrogation period)
Output:	16 line, 4 bits per digit, 4 decimal BCD (Other outputs optional - e.g., binary, ASCII, or analog)

PRICE: $1,400 and up depending upon output desired (e.g., sample depth, totalized flow, etc.), materials of construction, etc.

COMMENTS:

The Aquarius is a secondary device that shows great promise for measuring liquid levels in storm or combined sewer flows. The stilling well pipe can act as a damper to surges in liquid level by using a small hole to restrict flow to it. This could present plugging problems, and a configuration with many small holes, e.g., about 0.3 cm (1/8 in.) in diameter, will be preferred. In addition, the stilling well acts as a sort of acoustic waveguide, eliminating the echo problems that have plagued attempts to use many other types of acoustic level sensors in manholes, meter vaults, etc.

The unit must be considered still in the prototype stage. Only one has been delivered (to the U.S. Geological Survey) at the time of this writing. Advanced integrated circuit technology (CMOS) has been incorporated in the electronics design, and power requirements are low. Based on preliminary tests, battery life on Model 2002 should exceed one year. The device is all digital and so is immediately computer compatible.

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* Greater accuracies are optional.

MANUFACTURER: MEAD INSTRUMENTS CORPORATION
ONE DEY LANE
RIVERDALE, NEW JERSEY 07457
TELEPHONE (201) 835-5988

PRODUCT LINE: OPEN STREAM VELOCITY PROBE (TURBINE)

DESCRIPTION:

The Model HP-301 Open Stream Velocity Probe was designed for use in pollution control applications requiring the measurement of open stream water velocities*. Readings are reported to be instantaneous and accurate with no counters, timers, or lengthy test periods required. All readings are direct and may be made by untrained personnel. The adjustable head of the probe allows its insertion into pipe ends and vertical velocity measurements. The unit consists of a hand held probe (Model PT-301) and a portable indicator (FI012P).

The PT-301 Probe consists of a low inertia Delrin turbine mounted in a protective shroud at the end of an aluminum handle. The turbine, when immersed in a flowing stream, rotates at a speed in direct linear relationship to the fluid velocity. A small magnet sealed within the turbine hub produces an electrical pulse in an adjacent induction transducer for each rotation. The frequency of these pulses is thus also a direct measure of the fluid velocity. The FI-12P indicator is actually a portable frequency meter or frequency-to-DC converter. It amplifies and conditions the pulses to drive a meter indicator in a direct relationship to their frequency. The indicator scale is calibrated to read in the desired units of fluid velocity. The electronic system is stable, accurate, and all solid state. It is drift-free and requires no operational adjustments. All power is obtained from a set of eight standard "C" size flashlight batteries. The current drain is less than that of a normal flashlight bulb.

SPECIFICATIONS:

Various single or dual ranges are available up to 4.57 m/s (15 fps) water velocity, with 3 m/s (10 fps) being standard. The threshold of operation is approximately 0.08 m/s (0.25 fps) for all ranges.

Indicator:	250°, 5.6 inch long scale; weight 2.04 kg (4.5 lbs)
Probe:	Adjustable handle; weight 0.76 kg (20 oz)

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* Includes measurement of industrial or municipal pollution entering streams or rivers and flow out of large pipes or ducts.

PRICES:

HP-301-A	OPEN STREAM VELOCITY PROBE, portable, battery operated. Complete with indicator, probe, and case. Ready to use. Single range	$420.00
HP-301-A2	As above except dual range	$445.00

COMMENTS:

The lack of any recording provisions will be a handicap in all but brief survey work. The unit is designed for attended operation, so fouling should not present too great a problem except in the dirtiest flows.

MANUFACTURER: MERIAM INSTRUMENT
DIVISION OF THE SCOTT & FETZER COMPANY
10920 MADISON AVENUE
CLEVELAND, OHIO 44102
TELEPHONE (216) 281-1100

PRODUCT LINE: ORIFICE PLATES AND METER TUBES: PITOT TUBES: LAMINAR FLOW ELEMENTS: DIFFERENTIAL PRESSURE READOUT AND RECORDING INSTRUMENTS

DESCRIPTION:

Meriam manufactures three differential-pressure type primary elements. Their standard orifice plates are 0.3 cm (1/8 in.) thick 304 stainless steel, but can also be fabricated from monel brass or other materials on special order. Raised-face orifice flanges are offered for line sizes from 1.3 to 58 cm (0.5 to 24 in.); standard orifice meter tubes range from 2.5 to 30.5 cm (1 to 12 in.). Other sizes may be available on special order. Meriam also manufactures simple impact tubes of stainless steel in lengths from 25.4 to 101.6 cm (10 to 40 in.) and produces a wide variety of laminar flow elements, which are differential pressure producers operating on capillary flow principles and are normally used to measure gas volume rates of flow. None of the foregoing is deemed suitable for measuring typical storm or combined sewer flows, and they will not be discussed further.

Meriam manufactures a very wide line of U-type, well-type, and inverted manometers together with a complete range of scales for many applications. Of greater interest in the wastewater field is their bellows D/P Series 1100 line of differential pressure indicators which are schematically illustrated in Figure A. Operation of the Meriam

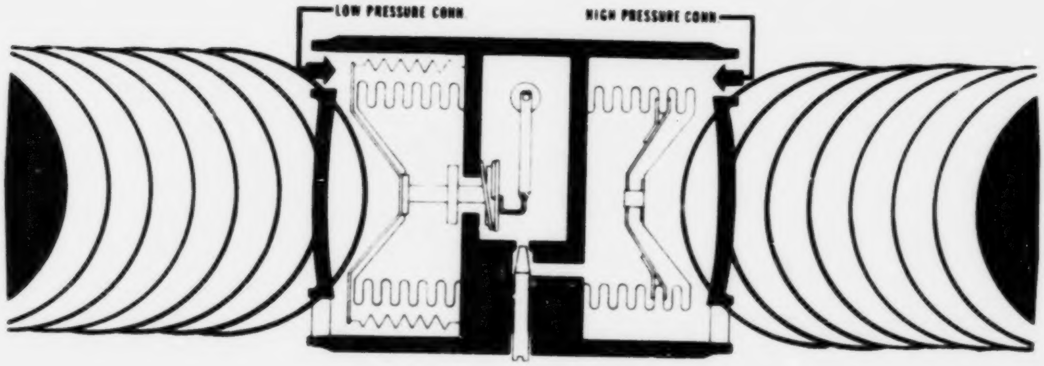


Figure A

Hydraulically Connected Differential Pressure Unit is based on the interaction of two opposed bellows attached to a machined center plate. All space enclosed by the two bellows is completely evacuated and fluid filled. The low pressure bellows shaft is connected by a linkage to transmit bellows motion to the output shaft. Pressures from the actuating source are introduced to both sides of the bellows system through either set of taps in the high and low pressure housings. When pressures on both high and low pressure bellows are equalized, the unit remains at zero. As differential pressure increases, the high pressure bellows contracts, forcing fill fluid through the pulsation dampener passage around the overrange valves into the low pressure bellows. This causes the low pressure bellows to expand and the attached shaft to move outward. Through linkage, the linear motion of the bellows shaft is translated into angular rotation of the output shaft. Movement of fluid from high pressure into low pressure bellows continues until the force created by the differential is equalled by the tension on the range springs. This unit is designed for sustained measurement and fast response speed. Overrange protection helps assure long periods of trouble free service. Temperature compensation assures accuracy under various adverse operating conditions. The bellows are fabricated of stainless steel, steel, monel, aluminum and others. They require no lubrication for life and include an externally adjustable pulsation damper.

Meriam Series 1300 recording flow meters are designed to work with the D/P bellows units. Spring-wound or electric chart drives in a variety of chart rotations are available. Also available are integrators, as well as pressure and temperature pens.

MANUFACTURER: METRITAPE, INC.
77 COMMONWEALTH AVENUE
WEST CONCORD, MASSACHUSETTS 01742
TELEPHONE (617) 369-7500

PRODUCT LINE: LIQUID LEVEL MONITORS AND ACCESSORIES

DESCRIPTION:

The unique and patented METRITAPE level sensor, schematically depicted in Figure A, consists of precision-wound linear, resistive helix held away from high-strength conducting base strip by thin and stable insulation layer along edges and back. A composite outer jacket encloses and protects the inner winding system, and acts as a diaphragm to receive the pressure of surrounding material. Positive or negative pressures are balanced by pressure-equalizing breather mounted at sensor top. The resultant continuous METRITAPE sensor is suspended from above throughout the full liquid height (see Figure B). As the liquid rises, the length of unshorted resistance helix, extending from the top to the liquid surface, decreases. The resulting uniform resistance change with level change may be read locally or transmitted thousands of feet over a simple leadwire pair, for remote level indication, alarms, and controls.

METRITAPE claims a number of advantages for its gaging systems, including.

- The sensor produces highly accurate readings of material levels, generally to better than ±0.1% (in liquids) and independent of depth; long term stability of output is that of a precision wirewound resistor.
- The transducer essentially has no moving parts, generates its electrical signal directly at the point of measurement (the air/liquid interface), and eliminates the need for moving floats, pulleys, guy wires, linkages, compressors, air dryers, mercury columns, etc.
- Level measurements are substantially independent of material specific gravity, product or air temperature, and gas pressure or vacuum above the material surface.
- Sensors can transmit their electrical outputs directly, without preamplifiers or electromechanical converters, for distances of several thousands of feet, at low impedance level and via low-cost signal-wire pairs, without significant accuracy loss.

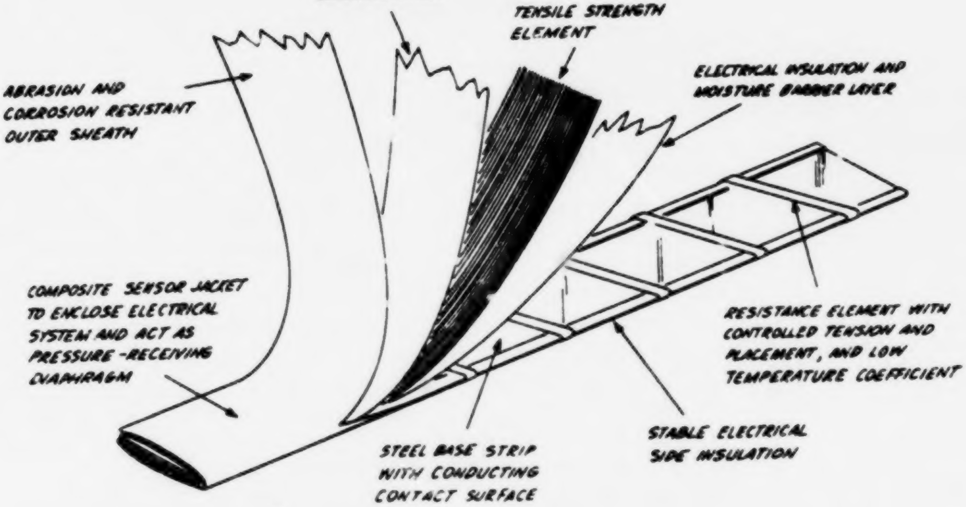

BARRIER LAYER
TENSILE STRENGTH ELEMENT
ABRASION AND CORROSION RESISTANT OUTER SHEATH
ELECTRICAL INSULATION AND MOISTURE BARRIER LAYER
COMPOSITE SENSOR JACKET TO ENCLOSE ELECTRICAL SYSTEM AND ACT AS PRESSURE-RECEIVING DIAPHRAGM
RESISTANCE ELEMENT WITH CONTROLLED TENSION AND PLACEMENT, AND LOW TEMPERATURE COEFFICIENT
STABLE ELECTRICAL SIDE INSULATION
STEEL BASE STRIP WITH CONDUCTING CONTACT SURFACE

Figure A

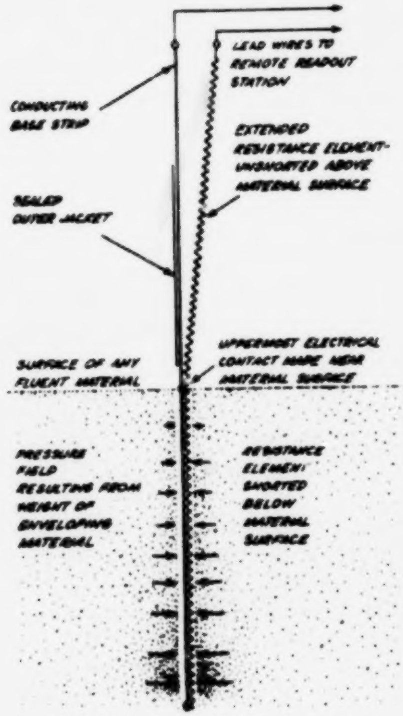

LEAD WIRES TO REMOTE READOUT STATION
CONDUCTING BASE STRIP
EXTENDED RESISTANCE ELEMENT-UNSHORTED ABOVE MATERIAL SURFACE
SEALED OUTER JACKET
UPPERMOST ELECTRICAL CONTACT MADE NEAR MATERIAL SURFACE
SURFACE OF ANY FLUENT MATERIAL
PRESSURE FIELD RESULTING FROM WEIGHT OF ENVELOPING MATERIAL
RESISTANCE ELEMENT SHORTED BELOW MATERIAL SURFACE

Figure B

- The sensor electrical output is suited for real-time computer monitoring and automatic control.

- Metritape systems can provide local analog level readout at the top, as well as analog or digital display at one or several remote locations.

- For highly critical automation systems, two sensors (having small cross-sectional area) can be mounted back-to-back to provide continuous and automatic self-checking.

- Frequency response of the sensor is sufficiently fast to allow oceanographic wave motions to be accurately measured and recorded.

A METRITAPE level system (see Figure C) generally consists of the following parts: (1) Metritape sensor and capillary breather assembly; (2) Electrical signal-conditioning and alarm circuitry, usually in NEMA-style panel box; and (3) Level readout display (analog and/or digital), plus adjustable level alarms with indicator lights and annunciator flasher and horn. For remote signal transmission, signal conditioning circuits are used to drive encoding and telemetry equipment, or may drive an analog strip-chart recorder or digital printer for permanent recording.

The styles of Metritape liquid-level sensors most commonly used in water, wastewater, and sewage applications are described below. These include general-purpose, corrosion-resistant, and ruggedized sensor constructions, and two basic sensor resolutions, general-purpose and moderate precision. The company expects in the near future to introduce precision liquid sensor Types PLS and PLS/S, having increased resolution for average deviations in the 0.003-0.006m (0.01-0.02 ft) range.

Type LS General-Purpose - Useful in water, petroleum, municipal sewage, and industrial wastewater not having high concentrations of chemical solvents or corrosives. The outer wetted jacket is adhered Mylar polyester, and the sensor is protected on three sides by an extruded bumper-strip of chlorinated vinyl (CPVC). Nominal sensor outer dimensions are 3.6 x 0.3 cm (1.4x0.25 in.), with OD of the upper cap being 3.8 cm (1.5 in.). Resistance helix has nominal 1.3 cm (0.5 in.) winding pitch, 30 ohms per foot, and temperature coefficient of 0.0001 ohm/ohm/°C. Available in lengths from 1.2 to 305m (4 to 100 ft), sensor average deviation is ±0.1 ft) or better, substantially independent of sensor length. The stabilized Type LS/S provides accuracy upgrading. The type LS sensor is designed for an outdoor ambient temperature range of approximately -30° to +60°C (-20° to +140°F), unheated product, 0 to ±10 psi maximum pressure of vacuum. The sensor is supplied with capillary breather assembly and cast aluminum mounting box 15x15x10 cm

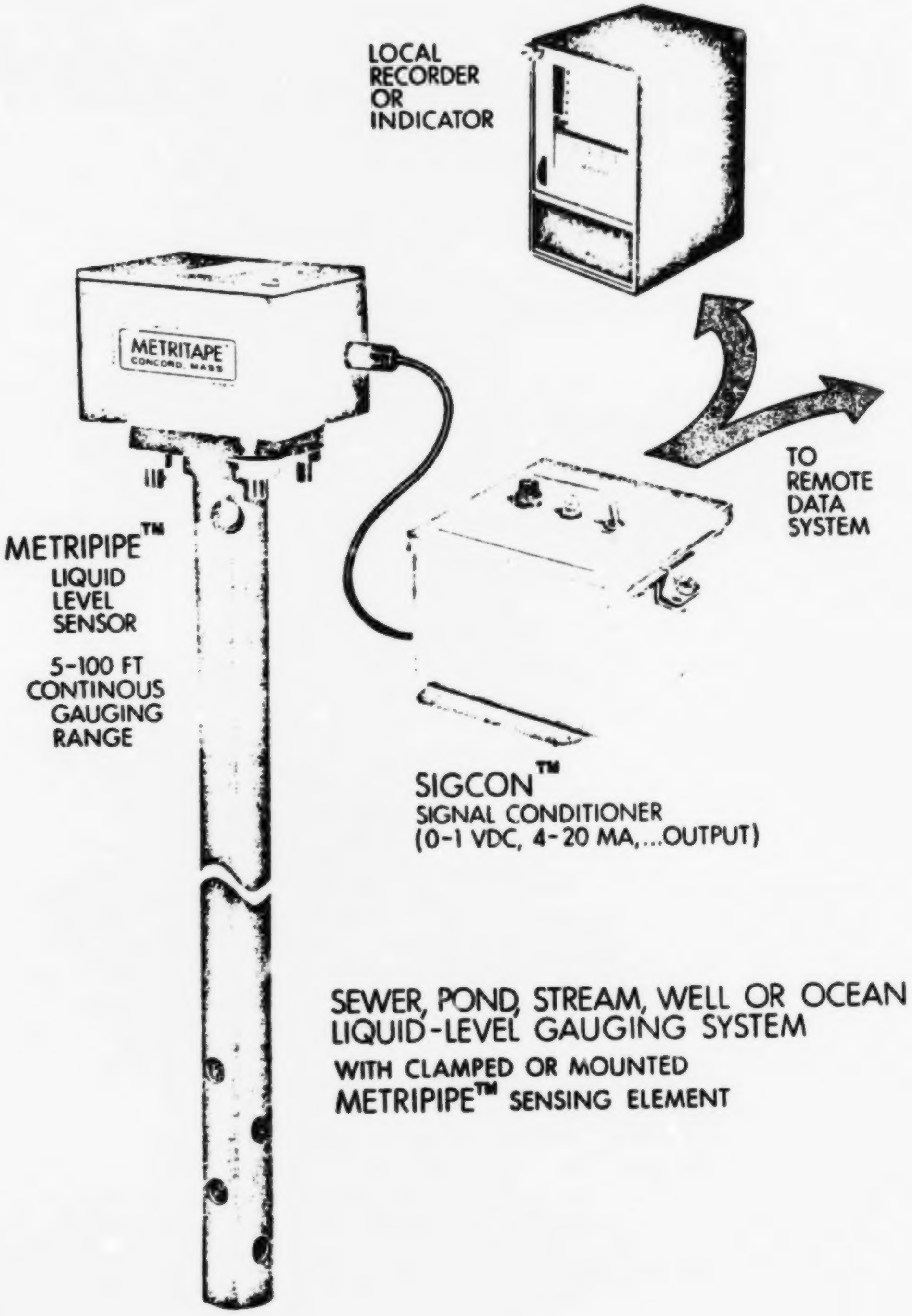

LOCAL
RECORDER
OR
INDICATOR
METRITAPE
CONCORD, MASS
TO
REMOTE
DATA
SYSTEM
METRIPIPE™
LIQUID
LEVEL
SENSOR
5-100 FT
CONTINOUS
GAUGING
RANGE
SIGCON™
SIGNAL CONDITIONER
(0-1 VDC, 4-20 MA,...OUTPUT)
SEWER, POND, STREAM, WELL OR OCEAN
LIQUID-LEVEL GAUGING SYSTEM
WITH CLAMPED OR MOUNTED
METRIPIPE™ SENSING ELEMENT

Figure C

(6x6x4 in.). The type LS sensor can also be provided with flurocarbon outer jacket surface for non-stick release finish, designated Type LS(F); and for fast-response dynamic wave gaging, as Type LS-FR.

Type LS-CR Corrosion-Resistant - Has heat-sealed outer jacket to resist highly corrosive liquids and chemical solvents. Wetted jacket material is generally flurocarbon, but can be polypropylene; and protective CPVC channel holder is used whenever this material is compatible with materials to be gaged. Electric winding system is as defined above, resulting in comparable accuracy. Available in lengths from 1.2 to 152m (4 to 50 ft), and supplied with capillary breather assembly and stainless-steel or fiberglass mounting box.

Type MPLS Moderate Precision - For increased resolution and repeatability, the MPLS sensor has nominal 0.6 cm (0.25 in) winding pitch; low-temperature-coefficient helix material (0.00003 ohm/ohm/°C); 30 ohms per foot nominal helix resistance; compliant jacketing system, with outer wetted jacket adhered thermoplastic. Other characteristics essentially as in Type LS above.

Type LSR Ruggedized - For demanding liquid and slurry applications, including high head pressures, high-velocity impacting, turbulent slurries, and stream containing potentially damaging foreign matter. The sensor utilizes toughened and ruggedized outer jacket surface, and may require a perforated or slotted pipe mounting for effective stilling action, without interrupting the flow to the sensor face. This is included in "METRIPIPE" systems.

The SigCon 700 series signal-converter instruments convert the 2-terminal resistance output of Metritape or Metritemp sensor to any one of a number of standard voltage or current forms, such as 0-1 VDC, 0-5 VDC, 4-20 mA, etc. These instruments are normally line-powered, but can be battery-powered for special remote operation. Output of the signal converter can be used to drive analog or digital indicating meters, strip-chart recorders, pulse-code transmitters, or central readout and alarm consoles.

SPECIFICATIONS:

Metritape Sensor Type	Nom. Pitch (turns/foot)	Active Lengths	Nom. AD* (feet)	Avg. Devia. (feet)	Repeatability (feet)
Standard LS	24	10-110 ft	0.4-0.6**	±0.1	±0.05
Stabilized LS/S	24	5-15 ft	0.3	±0.06	±0.03
Standard MPLS	48	5-110 ft	0.3-0.5**	±0.05	±0.025
Stabilized MPLS/S	48	3-15 ft	0.25	±0.03	±0.015

* AD is sensor "actuation depth" defined as head of water required for positive helix contact to base strip; it is constant offset distance of uppermost electric contact below water surface.

** AD is governed by sensor length; increased to accommodate max. static head of longer sensors.

PRICES:

Prices vary depending upon system specifications. As an example, a MP/MPLS-10 "METRIPIPE" with a 3m (10 ft) operating range, a Signal Converter 701A signal converter, and dry-writing strip-chart recorder costs around $1,200.

COMMENTS:

The Metritape system may well find application in large, open-channel flow measurements as a secondary device in conjunction with suitable head-area primary devices. Its rather high activation depth precludes its use in smaller flows. It has apparently worked well in a number of combined sewer installations.

MANUFACTURER: MOORE PRODUCTS COMPANY
SPRING HOUSE, PENNSYLVANIA 19477
TELEPHONE (215) 646-7400

PRODUCT LINE: FLUIDIC FLOWMETER AND ACCESSORIES

DESCRIPTION:

Flowmeter - The SSPH fluidic flowmeter is a unique flowmeter consisting of a meter body, sensor, and a Q/I converter. The meter body is a fluidic oscillator whose frequency is linear with volume flow rate. The oscillations are detected by a flush-mounted sensor and are amplified and conditioned by the electronics to provide a digital pulse output for totalizing and an analog output linear with flow rate. The geometric shape of the meter body is such that, when flow is initiated, the flowing stream attaches itself to one of the side walls by means of the Coanda effect. A small portion of the flow is diverted through a feedback passage to a control port (Figure A). This feedback flow, acting on the main flow, diverts the main flow to the opposite side wall where the same feedback action is repeated (Figure B). The result is a continuous self-induced oscillation of the flow between the sidewalls of the meter body. The frequency of this oscillation is linearly related to the fluid velocity and, hence, volume flow rate.

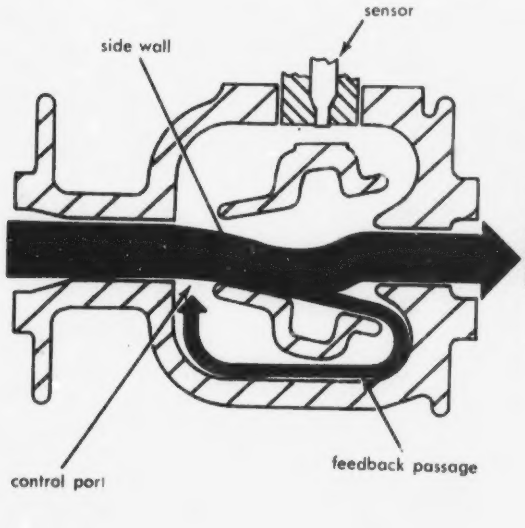


Figure A

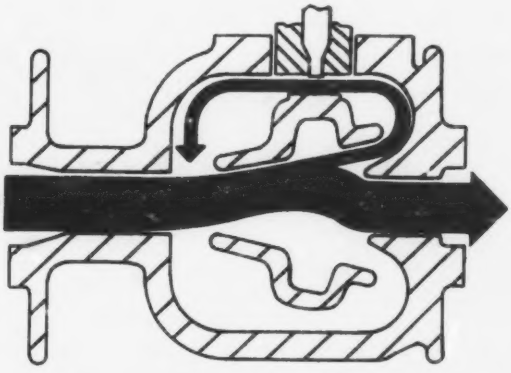


Figure B

As the main flow oscillates between the sidewalls, the velocity of the flow in the feedback passages cycles between zero and maximum. The feedback passages thereby provide a region with a substantial flowrate change in which to sense the frequency of the oscillating fluid in the meter body. This substantial variation in feedback flow is easily and reliably detected and results in a relatively noise-free sensor signal which is very strong (several hundred millivolts before amplification). The ruggedized, totally metal enclosed sensor (thermister) is further protected by being located in this region which is out of the main flow path. The flow and no-flow conditions at the sensor tip create corresponding high and low heat transfer conditions between the thermistor and the fluid which, in turn, cause the self-heated thermistor to tend to vary its resistance.

COMMENTS:

This interesting device is rather new on the market place and is available only in small sizes, up to 10 cm (4 in.), as yet. Its good accuracy, 30:1 rangeability, low pressure loss, and other advantages make it attractive for measuring pressurized flows in pipes. No information is available on coating effects of sewage on the thermal sensor, but they could be minimal. Clogging or plugging of the feedback passages could be a severe problem and, for this reason, no further description will be given.

MANUFACTURER: MUESCO, INC.
WESTERN DIVISION
674 N. BATAVIA STREET
ORANGE, CALIFORNIA 92668
TELEPHONE (714) 997-5860

PRODUCT LINE: PROPELLER METERS AND ACCESSORIES

DESCRIPTION:

Muesco offers a complete line of magnetic drive propeller meters under the "Rate A Flow" trade name. Included are Model TTM main line threaded tube meters, Model FHM fire hydrant meters, Model FTM flanged tube meters, Models CIFT and FST main line meters, Model SSC saddle meters, and Model ISM insertion meters. All of the foregoing were designed for use with water (or relatively clean liquids) and do not appear suitable for measuring wastewater flows.

Model OFM is an open flow propeller meter designed for open channel or submerged pipe outlet use. Available in 25.4 to 91.4 cm (10 to 36 in.) sizes, it features a three-bladed, non-fouling propeller molded from polyethelene plastic, a magnetic coupling, and bronze gear box. The meter transmission is completely sealed and permanently lubricated. Accuracy may be within ±2% if meter is used properly.

Model RC100 is an instrument that combines all features of a 30.5 cm (12 in.) diameter recording chart, full size indicator scale, and totalizer. A hermetically-sealed switch in the meter register-transmitter completes a pulse rate proportional to the rate of flow through the meter. This signal can be transmitted, for example, over leased telephone pairs, and is suitable for multiplexing. Chart drive is either 24 hour or 7 day rotation.

SPECIFICATIONS:

Model RC100

Accuracy:	±1% of full scale
Range:	24 to 1
Power:	11 VAC ±10%, 60 Hz
Output:	Optional 4 to 20 mA through 150 ohms

PRICES:	Model OFM	$340 - $425
	Model RC-100	$925

COMMENTS:

The open flow meter may find some application as a current meter for measuring storm or combined sewer flows. It does not appear suitable for unattended operation over appreciable periods of time.

MANUFACTURER: NB PRODUCTS, INC.
35 BEULAH ROAD
NEW BRITAIN, PENNSYLVANIA 18901
TELEPHONE (215) 345-1879

PRODUCT LINE: PORTABLE MANHOLE FLOWMETERS; V-NOTCH WEIRS; ROD GAGES

DESCRIPTION:

NB offers a line of portable float-in-flow flowmeters, portable V-notch weirs, and a rod meter (termed the FLO-ROD) for manual measurements of volumetric flow. Figure A shows a typical meter (Model H) installed in a manhole.

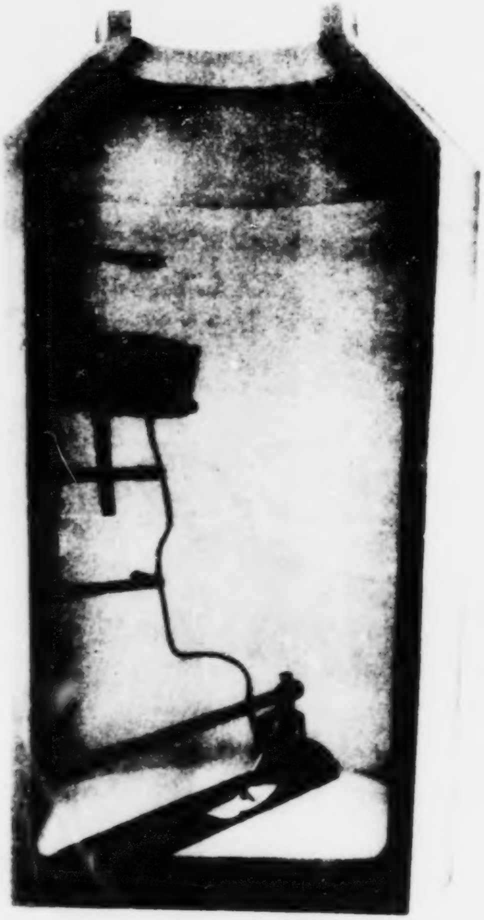
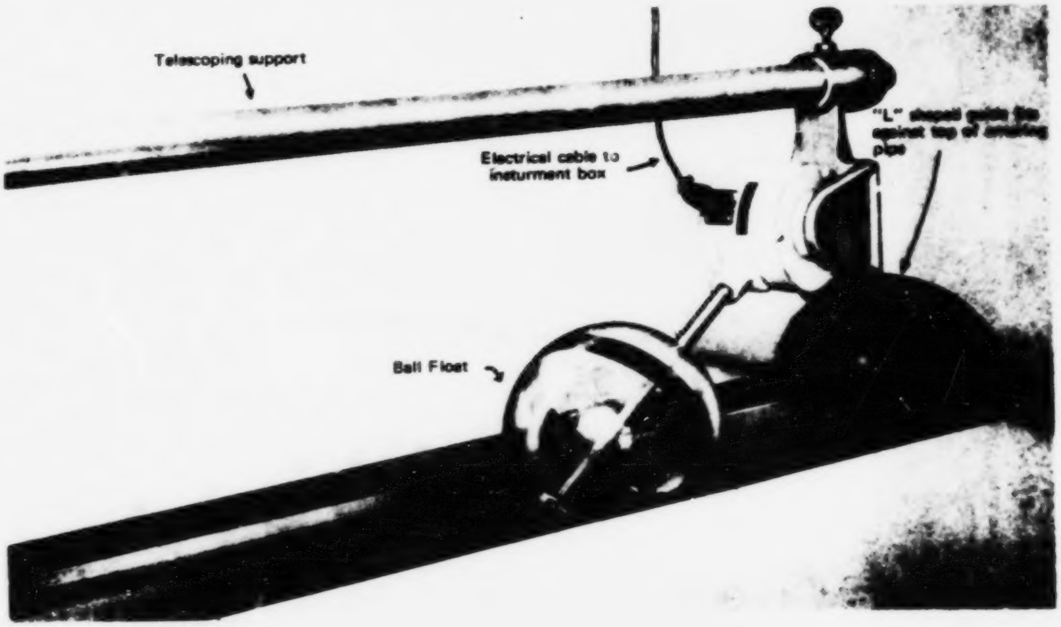


Figure A

Flowmeters

Series F Manhole Meter - This portable device consists of two basic parts - a transducer (Figure B), equipped with a telescoping support and ball float, and an instrument case containing a control box and strip chart recorder. A sensing unit inside the transducer determines changes in the water level in the channel by measuring the angle of inclination of the float arm (the ball float contacts the water in the channel). This information is then transmitted over an electrical cable to the recorder in the instrument case. Here, a continuous record of the elevation of flow passing through the manhole is made on pressure-sensitive chart paper. The recording, which runs at a uniform rate for up to 30 days, is unaffected by changes in temperatire, grease, etc. Longitudinal lines on the tape are used to show elevation of flow in percentage of pipe size, and cross lines indicate elapsed time in 15-minute intervals. In order to translate the tape recordings into gallons per 24 hours passing through the manhole, it is necessary to first determine the slope of the pipe. Available with each meter is a set of tables that can be used to convert elevation into rate of flow.


Telescoping support
Electrical cable to insturment box
"L" shaped guide fits against top of existing pipe
Ball Float

THE TRANSDUCER

Figure B

These meters are normally available for use in pipe sizes ranging from 20.3 to 111.9 cm (8 to 48 in). Since adjustment to various pipe sizes is accomplished by different length float arms, one basic unit can be used. Arms for pipes up to 1.8m (6 ft) are also available. The unit can be installed by one person in about 15 minutes. A Series G meter is offered at the same price and is virtually identical to the Series F except that the ball float is replaced by the scow float used in the Series H meter.

The power pack consists of four 7-1/2 volt rechargeable batteries that will power the meter for approximately 9 days on a single charge. Weekly charging is recommended, and a spare set of batteries and a charger are included with each meter.

Series-H Manhole Meter - This device uses a float-in-flow transducer similar to the Series-G flowmeter. One of the chief differences is that this model is programmed to account for the well-known variation in "n" (the Manning roughness coefficient) with flow depth in a circular pipe. This is especially important for low flows (under 25% of pipe diameter) and can result in accuracy improvements on the order of 20-30%. A solid state totalizer with L.E.D. display features no moving parts. The total maximum flow rate for the pipe at the site of interest is determined from NB tables and entered via a digital thumbwheel switch at the time of installation. All electronics are contained in a stainless steel submersion proof case. Two gel-cell batteries and a charger are also included with each unit. Battery life is 9 days on a single charge. A strip chart recorder is also provided as in the Series-G meters. Snap-in function boards adopt the Series-H meters for use with a variety of weirs and flumes as well as circular pipes.

Weirs

NB produces portable V-notch weirs in several sizes specifically designed to measure the amount of actual infiltration in newly constructed sewers and for measuring small discharges. Figure C shows a typical weir installation in a pipe.

V-notch weirs produced by NB are so designed that they can be installed by one person without the use of any tools in any pipe (vitrified, asbestos cement, concrete, or cast iron). Installation can be made in less than one minute. The V-notch weirs are cast from weather resistant aluminum alloy. The dial face is cut from transparent plastic and is calibrated for direct reading in gallons per 24 hours. Individual weirs are offered for six pipe sizes up to 38 cm (15 in). For larger standard sizes to 106 cm (42 in), adaptors can be purchased to be used in conjunction with the 38 cm weir (see Figure C).

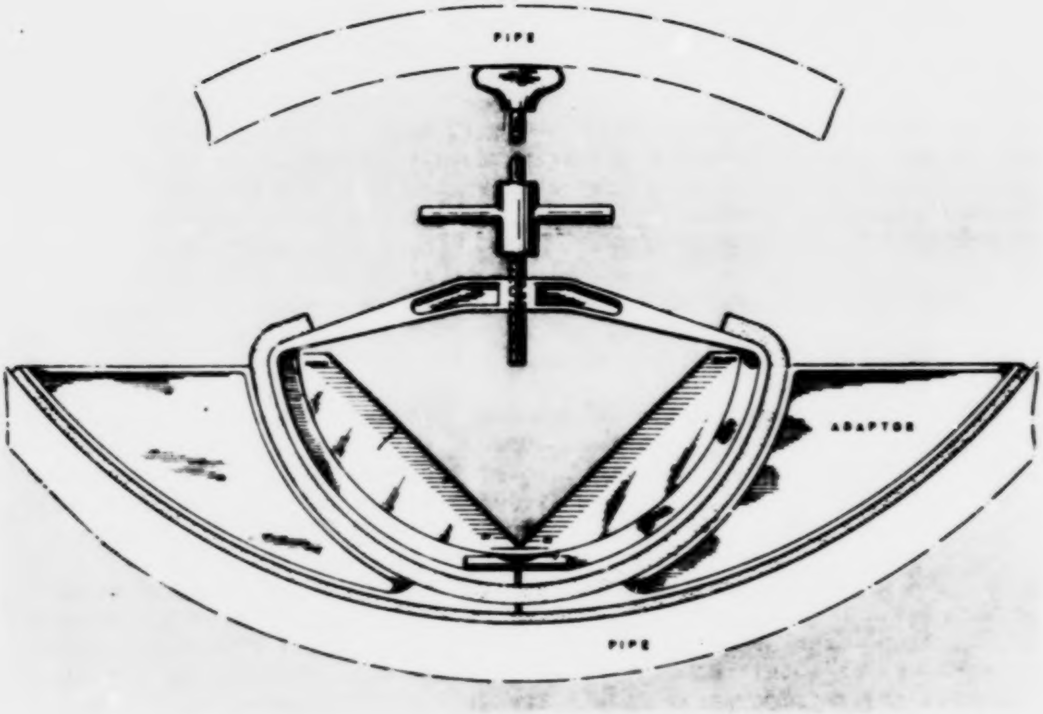


Figure C

Rod Meter

The FLO-ROD is a four-sided measuring device of 2.5 cm (1 in) square aluminum tubing calibrated on each side with a series of multipliers for approximate flow determination. Inserted into the center of the flow channel, a reading is taken at the water's surface. The volume of flow is then calculated from a special set of tables provided. Three FLO-RODs cover twelve pipe sizes, from 20.2 to 121.9 cm (8 to 48 in). Applications include: periodic checks of flows in sewers under construction; quick checks for leaks and other troubles; and infiltration-inflow studies.

SPECIFICATIONS:

Series-H Manhole Meter

Level Accuracy: ±0.0015m (±0.005 ft.)

Total Flow Recording: 999.999 units maximum

Flow Rate Indicator: 0-100% in 5% increments

Flow Rate Recorder 0-100% in 2% increments

Size-Electronics Case: 30.5x30.5x22.9 cm (12x12x9 in)

Total Shipping Weight: 30.8 kg (68 lbs)

PRICES:

Series-F & G Meters - - - - - - - - - - - - - - - - - - - $2,100

Series-H Meters - $3,000

Individual Weirs - $20 - $44

Weirs Adapters - $22 - $85

Complete Weir Kit & Case - - - - - - - - - - - - - - - $400

FLO-ROD - $30 - $50

COMMENTS:

The NB manhole meters would appear to be useful for measuring sewer flows at manholes over a limited range (many manholes will not allow accurate measurement with the pipe over about half full); however, these meters seem best suited for use with some better characterized primary device such as a flume, open flow nozzle, or weir. The portable V-notch weirs may be suitable for their intended purpose, but lack the range necessary for most flows of interest. The rod meters should only be used for making rough flow estimates.

MANUFACTURER: R. M. NIKKEL COMPANY
ROUTE 1, BOX B233
LIVE OAK AVENUE
OAKLEY, CALIFORNIA 94561
TELEPHONE (415) 625-3820

PRODUCT LINE: FLOW RATE TRANSDUCER

DESCRIPTION:

The BPN "FOTOFLOW" Series 800 flow rate transducer is a recently introduced insertion type device for fluid monitoring in the water industry. Although described by the manufacturer as an optical sensing type transducer, the primary element is a freely rotating flow sensing wheel. The wheel rotation is monitored by an optical sensor that offers no impedance to the flow sensing wheel and is easily removable from the line. A bi-directional capability is claimed over a nominal 100:1 range; accuracy of ±1% of rate and repeatability of ±0.5% are also claimed. Prices range from approximately $130 to $350 for the basic transducer without accessories.

COMMENTS:

Manufacturer recommends unit for use in "reasonably clear" liquids. It may find some use as a portable device for attended use in conducting wastewater surveys, but does not appear at all sutiable for unattended use in monitoring storm or combined sewer flows.

MANUFACTURER: NUSONICS, INC.
9 KEYSTONE PLACE
PARAMUS, NEW JERSEY 07652
TELEPHONE (201) 265-2400

PRODUCT LINE: SONIC FLOWMETERS

DESCRIPTION:

The NUSonics sonic flowmeter is a frequency difference type device designed for full pipe flow. Typically, it consists of two transducer assemblies, two mounting bosses, a transmitter and 15 feet of cable from each transducer assembly to the transmitter. At the customer's option, transducer assemblies may be supplied fully mounted in a flow tube or supplied in kit form for purchaser to install in his own flow tube. The transmitter enclosure may be NEMA 12, NEMA 4, or explosion-proof, at purchaser's discretion. An optional heater/thermostat for the transmitter permits cold weather operation.

Transducer assemblies are mounted through the pipe in such a way that they squarely face each other (Figure A) and are "wetted" by the liquid to be metered. Thus, the sonic pulse is not distorted by a pipe wall and is not subject to any refraction as it enters the liquid. It is claimed that this provides the most reproducible "received pulse" wave shape for best flowmeter performance. The transducers themselves are piezoelectric ceramic disks, which are protected by a cover fabricated from titanium or from an 8 to 10 mil Teflon coating over aluminum. The sonic pulse can be successfully transmitted and received through a surprising amount of organic or inorganic build-up on the transducers. Thus the NUSonics sonic flowmeter can function long after fouling has incapacitated a meter with moving parts (e.g., turbine meter) or a meter requiring electrical contact with the liquid (e.g., magnetic flowmeter).

To further minimize the potential effects of fouling and/or corrosion, the transducer assemblies may be provided with flushing ports (Figure B). Combined with Teflon-coated transducers, a periodic or continuous flush is particularly advisable for metering waste treatment streams and solids-laden plant effluent. The manufacturer notes that the NUSonics sonic flowmeter applies only to liquids or, in some cases, liquids with solids in suspension. Entrained gas bubbles may interfere. In general, the liquid must not excessively absorb and/or scatter sound.

NUSonics sonic flowmeters are available in sizes from 7.6 to 122 cm (3 to 48 in.) in fully assembled carbon steel, stainless and fiberglass flow tubes. Also available is a sonic flowmeter kit from which purchaser may convert his own pipe section into a sonic flowmeter in sizes up to 1.8m (6 ft).

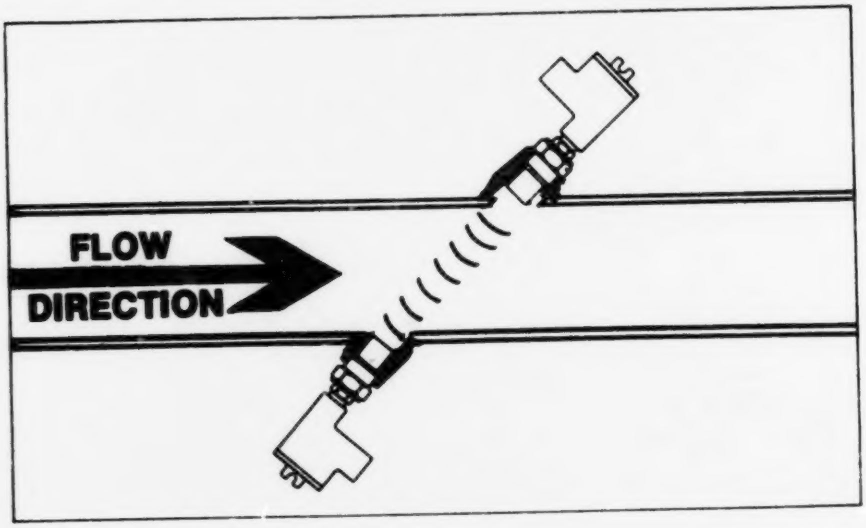

FLOW
DIRECTION

Figure A

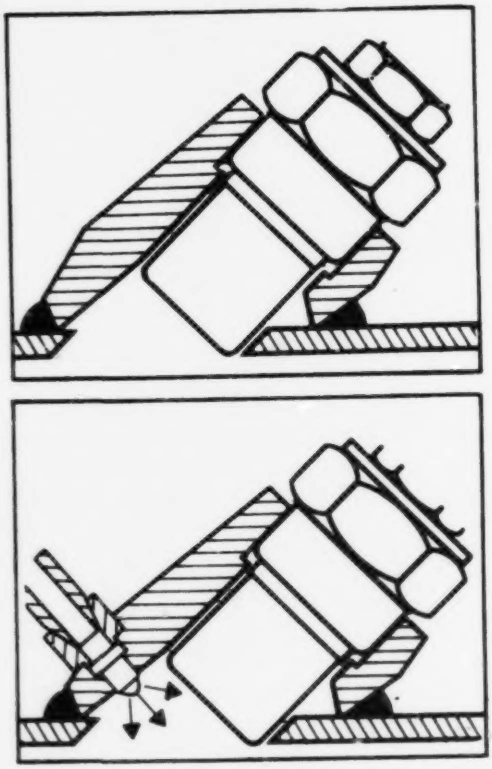


Figure B

NUSonics sonic flowmeters use similar electronics for all sizes. Thus, price increases relatively little with size. NUSonics sonic flowmeters are assigned meter factors based on precise transducer spacing measurements which will yield an absolute accuracy within ±1%. Where required, NUSonics will assist in actual calibration at an independent facility to achieve greater accuracy. Meter performance is independent of the inherent speed of sound of the liquid being metered but does vary with the shape and stability of the flow profile in the pipe. Variability for a given flow condition (repeatability) is ±0.2 percent of reading above a flow rate of 0.3 m/s (1 fps). Even better repeatability can be achieved with flow straighteners. Variability due to changes in meter factor with flow conditions (linearity) will be only ±0.75 percent over any practical flow range (up to cavitation) for Reynolds numbers over 100,000. Ranges of up to 100:1 may be achieved.

The NUSonics sonic flowmeter must be installed in straight pipe for best performance. For turbulent flow, the above performance is based on installations with the sonic flowmeter placed at least 20 pipe diameters downstream and at least 5 diameters upstream of any elbow, tee, or obstruction. Within shorter lengths, the device will yield correspondingly wider errors.

Various flow totalizers, rate meters, and chart recorders are available to receive the transmitter outputs (0-10 VDC; 4-20 or 10-50 mA.

PRICE:

Prices vary with specifications, but an explosion-proof unit for a 20.3 cm (8 in.) pipe with remote readout costs under $3,000.

COMMENTS:

A major disadvantage of this unit for many wastewater installations is the necessity for the transmitter to be less than 4.6m (15 ft) from the flow tube.

MANUFACTURER: OCEAN RESEARCH EQUIPMENT, INC.
FALMOUTH, MASSACHUSETTS 02541
TELEPHONE (617) 548-5800

PRODUCT LINE: ULTRASONIC FLOWMETERS

DESCRIPTION:

O.R.E. Model 7000 ultrasonic flowmeters are custom designed to meet each customer's application, and no standard product data sheets or brochures can be prepared. However, O.R.E. feels that it has delivered more of these devices for open channel flow measurement than any other U.S. manufacturer. The following information was obtained by private letter and telephone communication.

Basically, the Model 7000 ultrasonic flowmeter can be used either to measure line velocities along a single acoustic path or to measure total flow in either open or closed conduits over four or more acoustic paths and integrating the line velocities. The basic electronics package can handle a wide range of transducer frequencies (depending upon path length) and can sequentially compute total flow for up to four separate meter sections.

Most of the open-channel systems have been applied to rather large flows, e.g., Columbia River at Grand Coulee Dam, Willametta River at Portland, Oregon, etc. A typical installation near Hemet, California measures an inlet canal to Lake Skinner. This system gives the volume of flow directly by integrating the velocities from up to nine pairs of sensors (depending upon depth).

Systems can be provided for use in manholes, but 110V power is required. Unattended operation of two weeks is typical, at which time a paper tape is changed. Very little maintenance is required, and it will be about one year before any failures occur that would require significant repair. The electronics package is designed to withstand and operate over a 0°-50°C (32°-122°F) temperature range.

Some error (10-15%) can be expected at very low velocities, e.g., 0.03 m/s (0.1 fps), but the systems are quite accurate over the velocity range of 0.15-15 m/s (0.5-50 fps). Meters have been tested in 0.6m (2 ft) and 1.2m (4 ft) pipes in the Alden Research Laboratories of Worcester Polytechnic Institute with accuracies of better than 1%.

PRICES:

Pricing of systems is based upon the particular design for a given application, but a four-path system flowmeter would cost between $20,000 and $40,000.

MANUFACTURER: THE PERMUTIT COMPANY
DIVISION OF SYBRON CORPORATION
E49 MIDLAND AVENUE
PARAMUS, NEW JERSEY 07652
TELEPHONE (201) 262-8900

PRODUCT LINE:

PRIMARY DEVICES - VENTURI TUBES, FLOW TUBES, PARSHALL FLUMES, PARABOLIC OPEN FLOW NOZZLES

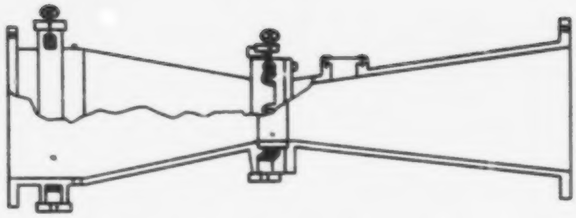
SECONDARY DEVICES - TRANSMITTERS, RECORDERS, TOTALIZERS

DESCRIPTION:

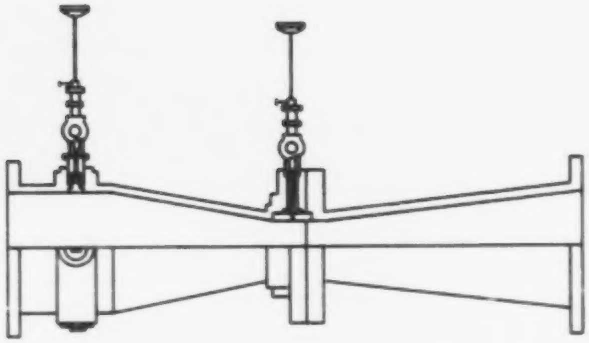
Permutit, a division of Sybron Corporation, manufactures a line of both primary and secondary devices for flow measurement. The primary devices include both standard and inexpensive venturi tubes, fiberglass Parshall flumes, parabolic open flow nozzles, and a patented flow tube known as the Permatube. Permutit also offers a variety of secondary instruments such as the float-in-flume transmitter used with Parshall flumes, electronic and telemeter transmitters, recorders, and totalizers.

Venturi Tubes - Tubes specifically designed for sewage, sludge, and trade wastes are the types VS, VTJ, and CTJ. These tubes are differential pressure metering devices for installation in closed piping systems. Types VS and VTJ have low head loss - less than 22.4 cm (9 in.) of water at maximum flow when used with a 10:1 range meter. A claim made for the types VS and VTJ is that metering by these devices is the least affected by upstream disturbances than by any other differential-pressure device. The simplex type CTJ Venturi tube is a one piece construction device of cast iron which minimizes manufacturing costs and comes in a variety of sizes to meet most flow requirements.

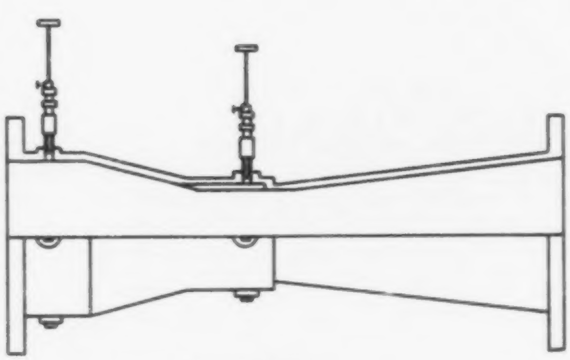
The Type VS and VTJ tubes (Figure A) are similar in construction to the type VT (cast iron with bronze throat liner) but have special design features which make them suitable for sludge and sewage. The type VS design includes a clear water flushing disconnector, four manual cleaning valves at both the main and throat sections (which may also be operated pneumatically or hydraulically), and cleanout holes at top and bottom of each annular pressure belt. This protects against fluids containing sediment or substances which may tend to clog the piezometer openings. Continuous backflushing is available as an option. This single-tap, type VTJ has pressure belts at the main and throat which contain a bushing which permits the use of only one piezometer tap and cleaning valve at each of these locations; thus,



TYPE VS - FOR SEWAGE



TYPE VTJ - FOR SLUDGE



CTJ TUBE
PLAN VIEW

Figure A

anti-clogging protection is provided against sludge or floating particles.

The less expensive CTJ design provides for single taps at the main and throat connections, and a bronze throat liner. A hand-operated bronze cleaning valve is located at each pressure connection.

Flow Tubes - Permutit has developed the Permutube (patent pending), a flow tube which has many performance advantages claimed for it. Among these are:

- Greater accuracy over wide operating range, achieved by greater pressure differential at lower velocity, without adversely affecting overall head loss.

- Low overall head loss, measured as a percentage of pressure differential.

- Stable coefficient over wider operating range of velocities and pipe Reynolds numbers lower than that obtained with any conventional venturi tube.

- Minimum laying length assures easier installation and provides greater flexibility of location.

The key to this proprietory design is the ramp and throat design as indicated in Figure B. It is available as an insert type, or with flanged ends in a choice of materials and complete range of sizes. Flanged end Permutubes are made of close-grained, high tensile strength cast iron with a bronze throat liner. An annulus averaging ring in the throat section ensures an accurate reading with only a single tap in the main. Tube ends are standard 56.7-kg (125-lb.) or 113.4-kg (250-lb.) flanges. Insert Type Permutubes are available with reinforced polyester fiberglass tube body and cast iron holding flange or body and flange of integral cast iron. Both types feature a bronze throat liner, annular ring in the throat, and a single tap at the main. Holding flange is made to fit virtually every style pipe flange.

For sewage handling, the addition of cleaning and flushing valve may not be necessary on the Permutube due to the self-cleansing effect of the flow over the ramps on the Pitot openings. Where severe sludge build-up is a possibility, cleaning and flushing valves can be supplied.

Parshall Flumes - The Simplex Parshall flume (Figure C) is constructed of polyester resin bonded glass fiber with reinforcing ribs to prevent

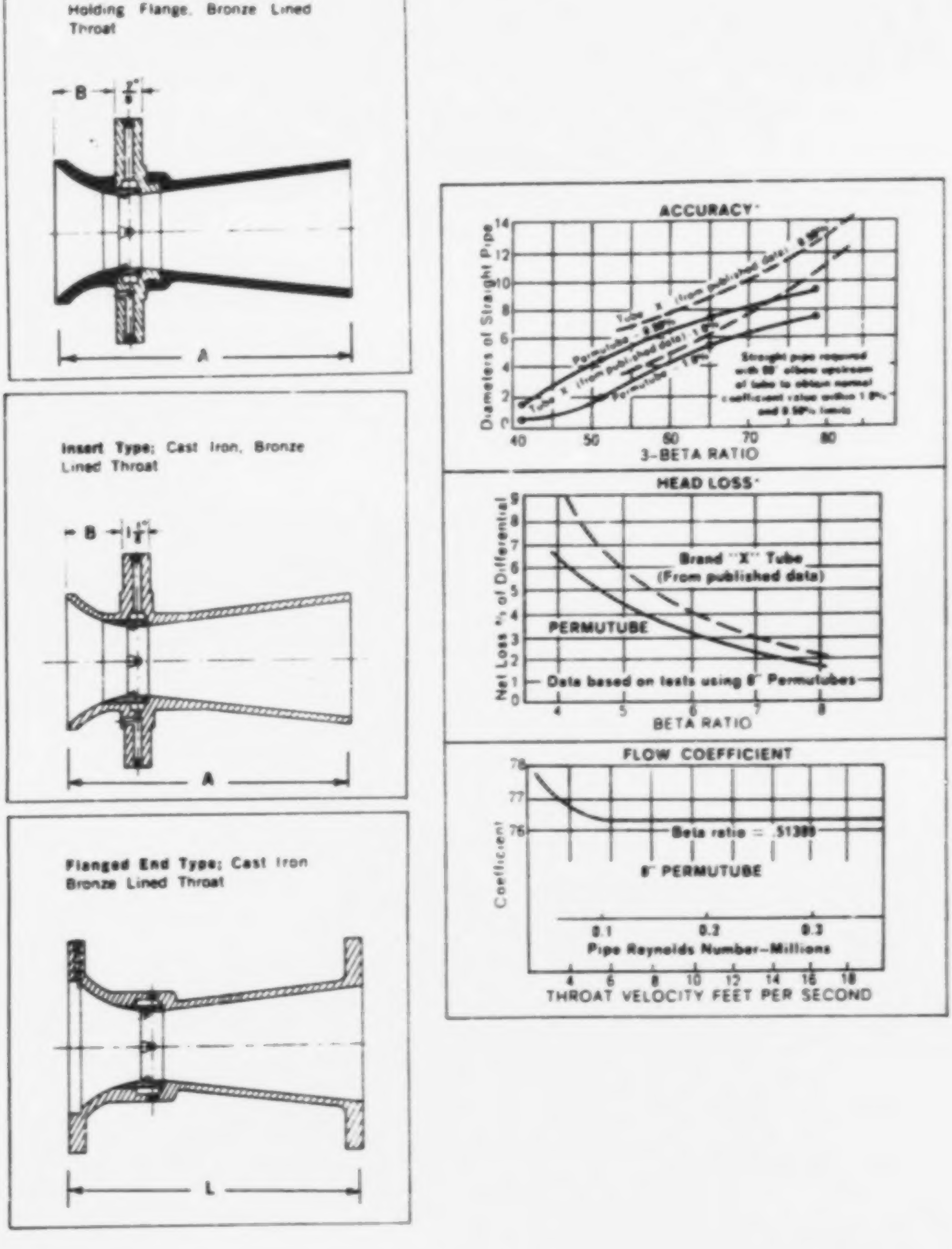

Insert Type; Fiberglass, Cast Iron Holding Flange, Bronze Lined Throat
B
A
Insert Type; Cast Iron, Bronze Lined Throat
B
A
Flanged End Type; Cast Iron Bronze Lined Throat
L
ACCURACY*
Diameters of Straight Pipe
14
12
10
8
6
4
2
0
40
50
60
70
80
3-BETA RATIO
Tube X (from published data) 0.50%
Permutube 0.50%
Tube X (from published data) 1.0%
Permutube 1.0%
Straight pipe required with 90° elbow upstream of tube to obtain normal coefficient value within 1.0% and 0.50% limits
HEAD LOSS*
Net Loss % of Differential
9
8
7
6
5
4
3
2
1
0
Brand "X" Tube (From published data)
PERMUTUBE
Data based on tests using 8" Permutubes
4
5
6
7
8
BETA RATIO
FLOW COEFFICIENT
Coefficient
78
77
76
Beta ratio = .51389
8" PERMUTUBE
0.1
0.2
0.3
Pipe Reynolds Number—Millions
4
6
8
10
12
14
16
18
THROAT VELOCITY FEET PER SECOND

Figure B

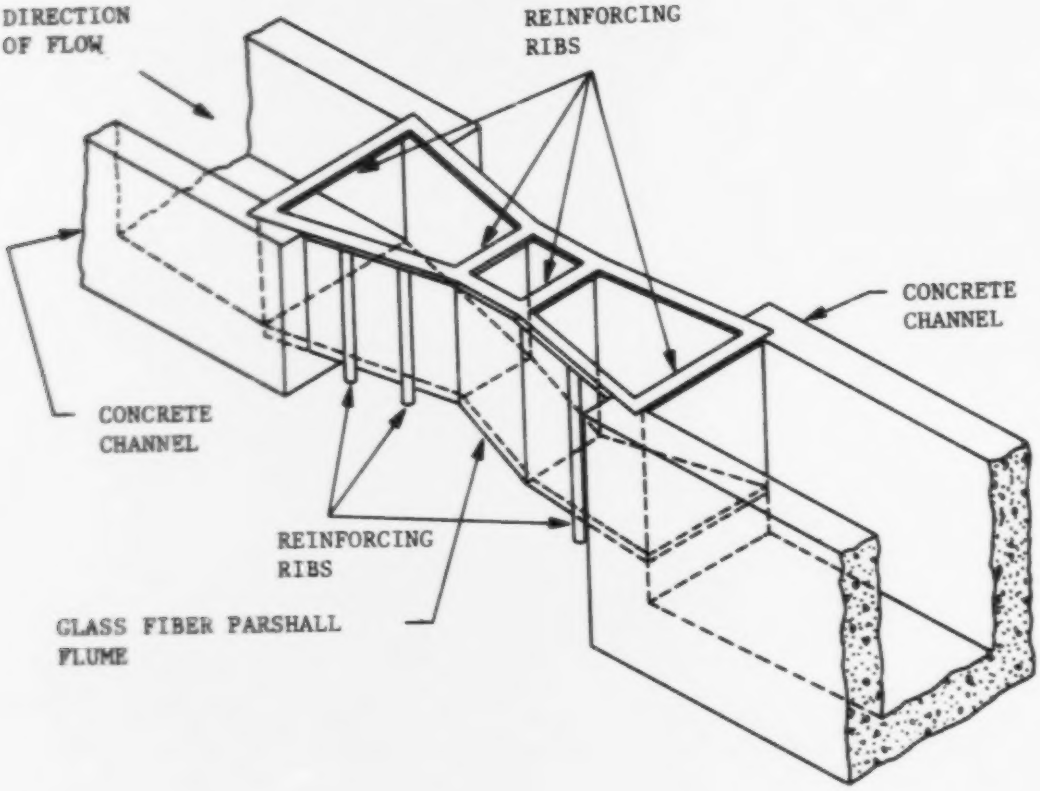

DIRECTION
OF FLOW
REINFORCING
RIBS
CONCRETE
CHANNEL
CONCRETE
CHANNEL
REINFORCING
RIBS
GLASS FIBER PARSHALL
FLUME

Figure C

warping, twisting, or buckling out of shape. The polyester resins are very resistant to erosion from the passage of solids or abrasives, making this flume suitable for sewage or industrial wastes flow. The flume is manufactured in integral units.

Parabolic Open Flow Nozzles - Permutit also markets two types of parabolic open flow nozzles, Types S and SFF. The Type SFF has largely superseded the Type S, which featured its own integrally cast sediment chamber, a gauge glass and setting scale (for calibration), and a manual cleaning valve assembly at the tap location. The Type SFF eliminates these features since its metering float arm rides directly on the flow stream. Most installations are now constructed with a transmitter in the pit, with the meter receiver located above the metering site or at some distance away in a more protected location. Both types are of cast iron construction and utilize the same principle of operation. The interior presents a smooth transition from circular to parabolic form, with no obstructions or pockets, straight inverts. This permits a gradually increasing velocity through the nozzle, thereby tending to provide a self-scouring action.

Float-in-Flume Transmitter - The Simplex float-in-flume transmitter is designed to continuously indicate the flow of sediment-laden liquids as it passes through a Parshall flume under gravity conditions. A similar device is available for parabolic open flow nozzles. Liquid flow is indicated by the direct sensing of the level of the liquids within the flume; flow data are transmitted either electrically or pneumatically to a remotely-located flowmeter.

The transmitter (Figure D) is mounted directly on the wall of the Parshall flume. A corrosion-resistant "ski" type sensor (float) rides directly on the surface of the liquid flow stream; it does not cause disturbance on the surface of the liquid or excessive oscillation in recording instrument. As the surface of the liquid rises or falls, depending upon the flow through the flume, the sensor changes its position accordingly. This movement produces proportional angular movement of the sensor arm and shaft on which it is supported.

For electric transmissions, the shaft arm angular movement is transferred to a stylus riding over a characterized cam which is corrected for non-linearity. The resultant linear signal, proportional to flow, is transmitted every 15 seconds, with a pulse duration varying from a fraction of a second to approximately 12 seconds. Three seconds of each 15-second period are required for the receiver to reset for the reception of the next signal.

For pneumatic operation, the shaft arm angular movement is transferred to a shaft carrying a cam characterized to the head quantity relationship

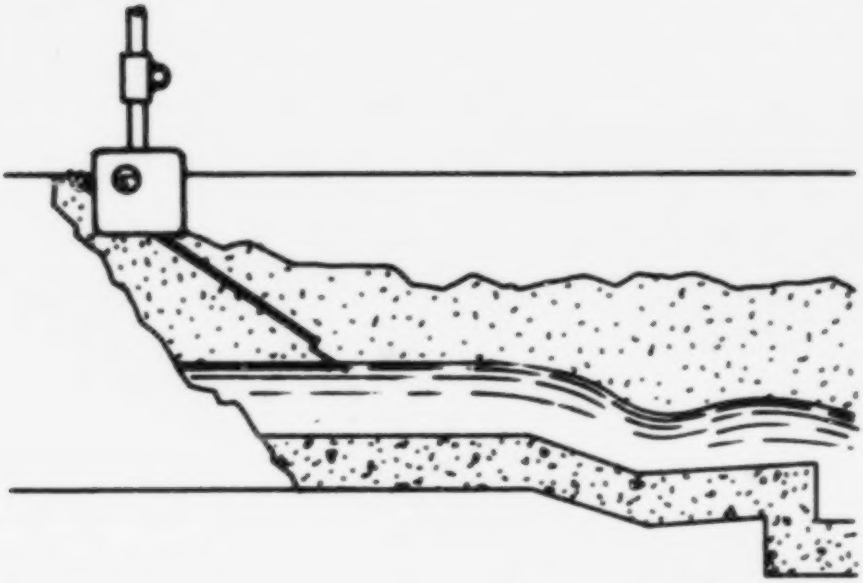


Figure D

of the flume. A pneumatic tracing device senses the profile of this cam and transmits a linear, 3-15 psig pneumatic signal through an amplifying relay to the receiver.

Advantages of this device include the following:

- Reduces installation space
- Faster responses to flow changes
- Reduces material costs - eliminates stilling wells, connecting piping and fittings, large float and cable, back purge system, etc.

Other Transmitters - Several other types of transmitters are offered. These include the Type K telemeter transmitter, which transmits an electrical signal through a two-or four-wire system to one or more systems, and the Type STRR transistorized, force-balance differential-pressure instrument with a 4 to 20 mADC transmission signal for liquid flow applications.

Recorders/Totalizers - These include a compact recorder which indicates and records fluid flow on a rectilinear strip chart and is actuated either mechanically, electrically, or pneumatically. Also offered is the Type STR-3 electronic recorder (solid state receiver) which can remotely record and indicate flow loss of head, pressure, etc. The totalizer can receive differential signals (electrical, mechanical, etc.) from the primary element.

SPECIFICATIONS:

Type CTJ Venturi Tube:	Flow capacities ranging from .2456 MLD (.0649 MGD) to 37.6179 MLD (9.9968 MGD) depending upon dimensions and type meters used. Weights ranging from 16.3 to 247 kg (36 to 544 lbs.)
Flow Tubes (Permutube):	Refer to graphs in Figure B for a comparison of accuracies, head loss, and flow coefficients.
Parshall Flumes:	Throat sizes ranging from 7.62 to 121.92 cm (3 to 48 in.); lengths ranging from 0.91 m to 3.27 m (36 to 131 in.); flexual strength of up to 21,000 psi.
Parabolic Open Flow Nozzles:	Inlet Diameters (Type S) - 15.2 cm to 106.7 cm (6 to 42 in.) Flow capacities (Type S) - to 10.295 MLD (2.72 MGD) for 106.7 cm size.

PRICES:

Prices not available at the time of this writing.

COMMENTS:

These devices were thoroughly discussed in Section VI and will not be commented upon here.

MANUFACTURER: PLASTI-FAB, INC.
11650 S.W. RIDGEVIEW TERRACE
BEAVERTON, OREGON 97005
TELEPHONE (503) 644-1428

PRODUCT LINE: FIBERGLASS PALMER-BOWLUS FLUMES, V-NOTCH WEIR BOXES, AND PARSHALL FLUMES

DESCRIPTION:

Plasti-Fab manufactures several primary devices in a variety of sizes. For example, Parshall flumes are available from 2.5 cm (1 in.) to 1.2 m (4 ft.) and with either 20.3 cm (8 in.) or 30.5 cm (12 in.) floatwells attached to either side as provisions for remote stilling wells. A head gage is molded into the side of all Plasti-Fab Parshall flumes for visual checking of flows. A 2.5 cm (1 in.) blow-out connection is also provided on the floatwell. All Plasti-Fab Parshall flumes are heavily ribbed for free-standing installation, and they may also be installed as liners in concrete. They feature 5 cm (2 in.) flanges on ends and top, with heavy angle bracing across the top flanges. These basic devices were discussed thoroughly in Section VI and will not be described further here.

MANUFACTURER: POLCON, INC.
AN AFFILIATE OF CARL F. BUETTNER
& ASSOCIATES, INC.
5106 HAMPTON AVENUE
ST. LOUIS, MISSOURI 63109
TELEPHONE (314) 353-5993

PRODUCT LINE: FLOW TUBE

DESCRIPTION:

The POLCON flow tube is a primary metering element designed for the measurement of wastewater flows in partially filled circular conduits. The tube is furnished in segments for insertion into existing piping systems through a manhole or other opening in the piping system. Figure A shows a typical flow tube installation.

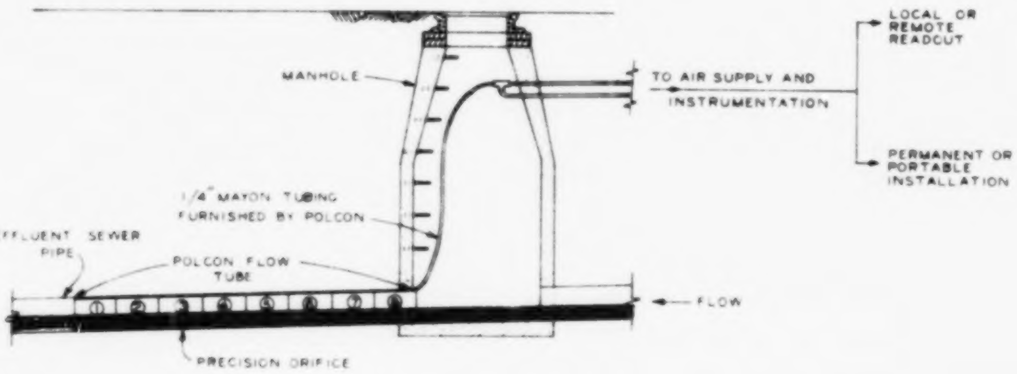

LOCAL OR REMOTE READOUT
MANHOLE
TO AIR SUPPLY AND INSTRUMENTATION
PERMANENT OR PORTABLE INSTALLATION
1/4" MAYON TUBING FURNISHED BY POLCON
EFFLUENT SEWER PIPE
POLCON FLOW TUBE
①
②
③
④
⑤
⑥
⑦
⑧
FLOW
PRECISION ORIFICE

Figure A

The POLCON technique of measuring flow is based on the establishment of a fixed relationship between the depth of liquid flowing in a smooth straight conduit and the rate of flow. In effect, it allows the Manning friction factor "n" to be factory determined, and the "POLCON" conversion tables account for its variability with flow depth. A uniform slope is also established. A precision orifice embedded in one segment of the flow tube permits the depth of liquid flowing to be measured by determining the air pressure required to overcome the height of fluid.

"POLCON" flow tubes provide a smooth, continuous liner inside an existing pipe and are sufficiently long to permit the bubbler to be located downstream from the manhole at a point where the flow tube and hydraulic slope are normally parallel. They are fabricated and machined in 30.5 cm (12 in.) long segments, eight of which are used in a normal installation. For troublesome installations, only four segments can be used, and at a sacrifice in accuracy. The entire tube is fabricated of PVC plastic, and "O" rings are placed on the exterior surface to prevent short circuitry of flow.

"POLCON" portable flow tubes are supplied in sizes to fit 15.2 to 45.7 cm (6 to 18 in.) diameter sewer pipes as standard. Larger or nonstandard diameters can be supplied on request. On installations where the nominal size "POLCON" wastewater flow tubes will not pass through the standard manhole cover, "POLCON" offers large diameter tubes which are installed as an integral part of the sewer. Large diameter tubes are furnished in steel or ductile iron, epoxy lined for lasting service, and fabricated as a single unit with no decrease in sewer diameter or carrying capacity. These are used for new construction or where low-cost wastewater flow measurements are required in existing large circular sewers.

"POLCON" also offers a complete line of instruments compatible for use with their wastewater flow tubes in both portable and permanent configurations. All portable units are built with rugged, lightweight fiberglass cabinets measuring 58.4 cm (23 in.) in diameter and 81.3 cm (32 in.) high. Model PIP-100 is powered by an external air supply connected to the built-in air control system. The cabinet contains a rota/purge meter, a 15.2 cm (6 in.) spring-wound recorder covering 0-38 cm (0-15 in.) of water range. Model PIP-101 differs only by the addition of a 14-day gas bottle that is locally refillable. Model PIP-102 features an air compressor and electrically-driven recorder, and also requires a 110-VAC external power source. Model PIP-112 combines the air compressor with a gas bottle back-up to avoid power failure effects. Options include a 20.3 cm (8 in.) recorder and a 7 day or 24 hour recorder.

SPECIFICATIONS:

Accuracy: Up to ±4%

Flow Capacities:

POLCON Model #	Sewer* Dia.	Quantity in GPM*				
		Slope				
		1%	2%	3%	4%	4%
SFT/PFT - 6	6"	178	251	308	356	398
SFT/PFT - 8	8"	254	360	440	509	569
SFT/PFT - 10	10"	531	751	920	1063	1188
SFT/PFT - 12	12"	977	1382	1693	1955	2186
SFT/PFT - 15	15"	1575	2227	2728	3150	3522
SFT/PFT - 18	18"	3358	4749	5817	6717	7510

* Metric Conversion Factors:
Inches x 2.54 = Dia. in centimeters (cm)
GPM x 3.785 = Liters per minute (LPM)

PRICES:

A total POLCON package (including an 8 to 10 inch-tube, sensor, and liquid level recorder) costs approximately $2,000 - $800 for tube and $1200 for sensor).

COMMENTS:

This device essentially provides a controlled flow section within the sewer in which (hopefully) the Manning formula can be applied with greater accuracy. Since slope-area methods such as this are not well-suited for flow determinations in many storm or combined sewers, its benefit would seem marginal at best.

MANUFACTURER: PORTAC
MIN-ELL COMPANY, INC.
1689 BLUE JAY LANE
CHERRY HILL, NEW JERSEY 08003
TELEHPONE (609) 429-0421

PRODUCT LINE: CURRENT METER FLOW TUBES

DESCRIPTION:

PORTAC Flow Tube - The PORTAC Portable Sewer Conduit Flowmeter is a patented device (Figure A) that has been used successfully by New York City's Department of Water Resources Industrial Wastes Control Section for sewer flow measurement. The meter, shown in the plan view of Figure B, is designed to create full pipe flow in the sewer conduit, thus making the area of flow constant. (A self-damming flap gate, also shown in Figure B, is provided for this purpose.) The only other variable is velocity and this is measured with an OTT current (velocity) meter (shown installed in Figure C). The number of revolutions made by the meter's propeller are totalized on a digital counter. By applying the specific formula supplied with a particular system, flow totals can then be calculated.

As shown in Figure B, suspended deflectors, which are removable, are constructed immediately upstream of the current meter's propeller. This is done to reduce or eliminate the possibility of damage to the propeller by hard, fast-moving objects such as wood. The deflectors also generally redirect pliable suspended materials, normally encountered in sewer wastes, away from the area around the propeller's rotation.

Easily mounted on and suspended with a placement rod, the device can be installed (or removed) by only two sewer workers, regardless of manhole invert contours. Some of the hydraulic and physical advantages claimed for the PORTAC flowmeter are:

- Velocity of approach is not a factor if a high velocity propeller is used on the current meter;
- Sewer grade may be any value;
- The system is as good or better than a flume or weir in terms of ease of installation; the tube can also be easily sealed to ensure that all flow is being gaged;
- The system is unaffected by surcharging or submersion; and

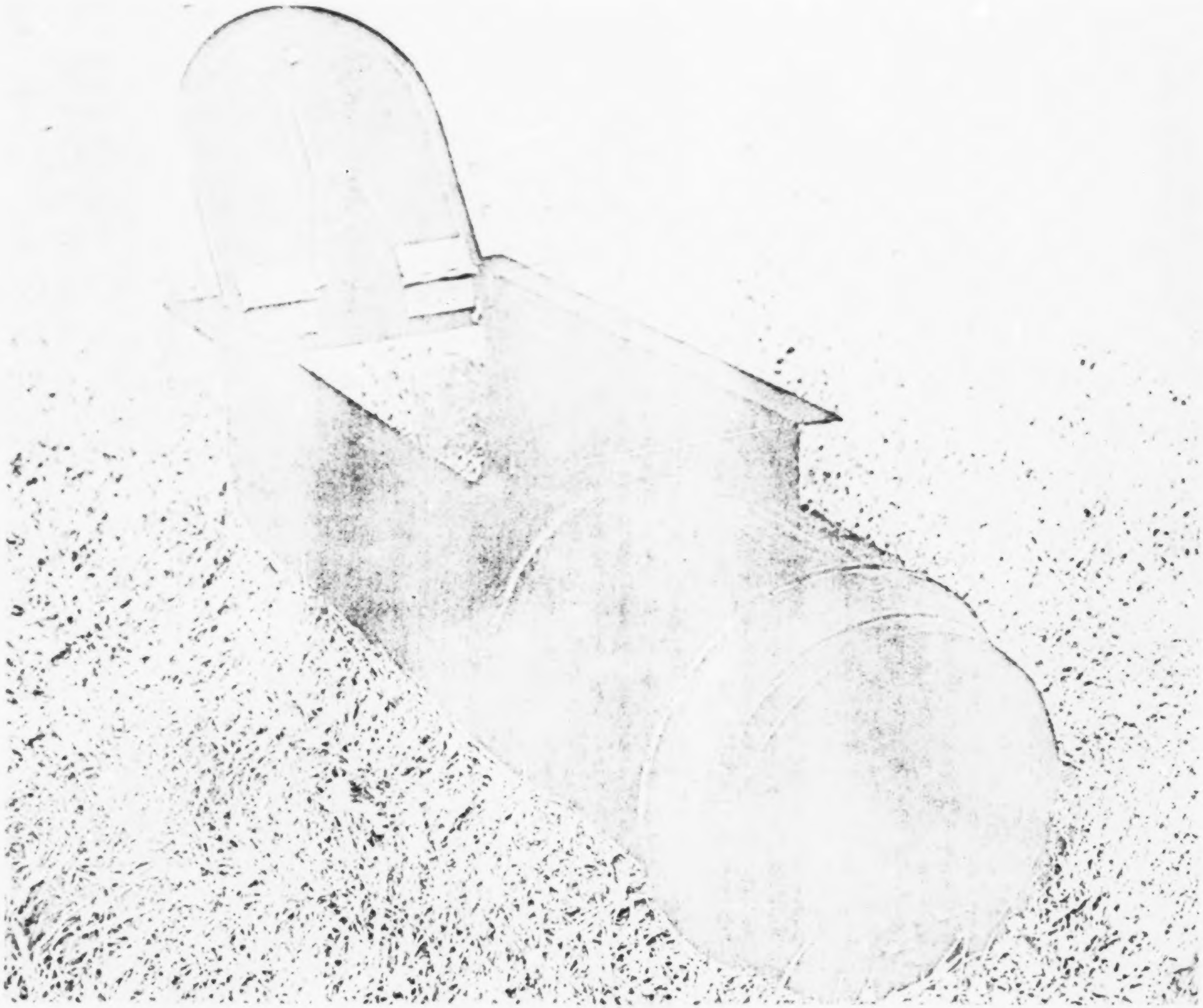


Figure A

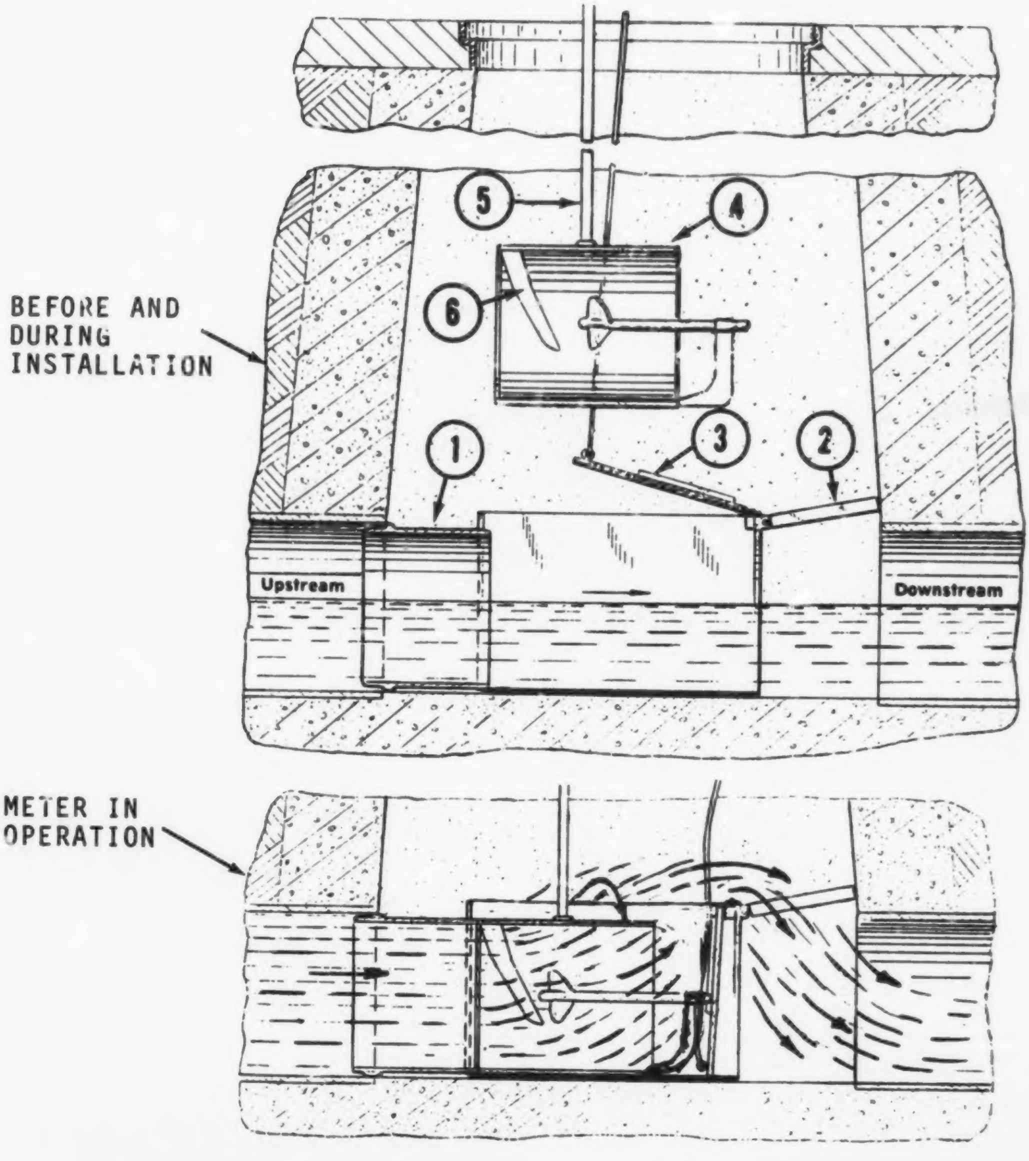

BEFORE AND DURING INSTALLATION
Upstream
Downstream
METER IN OPERATION

Figure B

Figure C

- The system does not need compressed air or AC power to operate, and thus is truly portable.

The flowmeter is fully adaptable for analog metering as well as strip chart recording. The standard metering package consists of: the flow tube; an OTT Model 10.002 current meter; and a three-digit, battery-operated counter model (F4). A five-digit counter (also battery operated), Model Z100, with other monitoring features* is also available, at additional cost. An optional current meter for use with PORTAC is the OTT Model 10.300 which has provisions for analogue strip recording.

Current Meters - In the OTT 10.002 standard unit shown in Figure D, signals are generated by means of a permanent magnet mounted on a worm sleeve which completes the circuit by way of an impulse device embodied in the meter following each revolution of the propeller. The device is

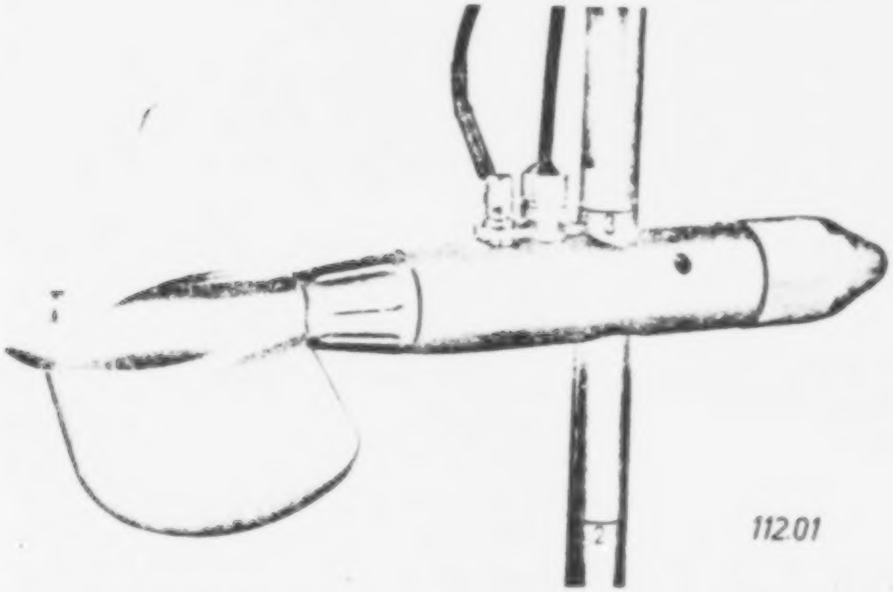


Figure D

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* e.g., audible indication of input pulses by a loud buzzer.

largely free of restoring forces and may be said to operate virtually without power. The diameter and pitch of the propeller to be used is determined by the maximum flow velocity of the water to be encountered. A special table is provided to enable proper selection.

Counters - the three-digit F4 counter (type 12.000) counts a maximum of 10 pulses per second and is suited for operation with the OTT 10.002 (C31) current meter, which generates a signal pulse at each revolution of its propeller. Two 1.5-volt "D" size batteries serve as the power source and allow up to 48 hours of continuous operation without battery replacement. A stopwatch is used in conjunction with this instrument.

The Z100 five-digit counter is capable of measuring the length of pulse cycles from voltage-free transmitters (e.g., current meters), up to a maximum of 20 pulses per second. It is powered by six 1.5-volt single-cell batteries sufficient for about 30 hours of operation, assuming 8 hours of operation each day.

SPECIFICATIONS:

PORTAC Flowmeter (Less Current Meter and Counter)

Accuracy:	±3%, when velocity flow exceeds .027 m/s (0.09 fps)
Line Sizes:	15.2 to 45.7 cm (6 to 18 in.) Nominal I.D.

PRICES:

PORTAC (Less Current Meter and Counter)	$815-$915
PORTAC Complete with Current Meter and Counter	$1150.00
Optional 5-Digit Counter (Z100)	$950.00

COMMENTS:

Although this unit has been used in some sewers, it does not appear well suited for general storm or combined sewer applications, since it must suffer all the deficiencies of a current meter and is available only in small sizes.

MANUFACTURER: RAMAPO INSTRUMENT COMPANY
MACOPIN ROAD
BLOOMINGDALE, NEW JERSEY 07403
TELEPHONE (201) 838-2300

PRODUCT LINE: TARGET-TYPE FLOWMETERS, RECORDERS, INDICATORS

DESCRIPTION:

The RAMAPO Instrument Company manufactures a flow meter probe (the Mark V) which is reported to be widely used for measuring industrial wastewater flows. The company also offers several other flowmeters, including the newly-developed Mark VI target flowmeters, and a variety of recording and indicating devices.

Mark V Flowmeter Probe - This device will measure most process fluids in pipelines. This is done by installing a flanged fitting into an existing pipeline (see Figure A). The strain gage force sensing element of this device has no bearings or other rotating parts. The electrical signal can be transmitted to remote locations or used for indicating, recording, controlling, and totalizing. The Mark V Flowmeter measures flow in terms of the dynamic forces acting on a fixed body in the flow stream. Bonded strain gages in a bridge circuit outside the fluid stream and shielded by stainless steel, translate this force into an electrical output proportional to the flow rate squared.

A modification of the standard Mark V Flowmeter Probe, a retractable probe, is also available for pipeline applications. This particular device can be installed in or removed from pressurized systems without causing a shutdown. The probe can be moved from line to line - even for widely varying line sizes - for sampling or spot checking of flows. Materials and specifications are generally the same as those for the standard probe.

Other Flowmeters - Less suitable for effluent flow measurements is the Mark V flowmeter for tube end and pipe connection applications. They are usable with slurries and some types of abrasive fluids, however. Accuracy is reported to exceed ±0.5 percent in flow ranges of approximately 10:1. Line sizes available are from 1.3 to 15.2 cm (0.5 to 6 in.) with any standard end fitting, with special sizes supplied upon request.

The Mark VI Target Flowmeter is a new product which has been developed for measuring flows of dirty liquids, slurries, etc. This flowmeter has no moving parts and no cavities to collect particles or entrap materials that can harden. Available in a wide variety of line sizes and configurations, it has operational performance characteristics similar to the Ramapo Mark V Target Flowmeter.

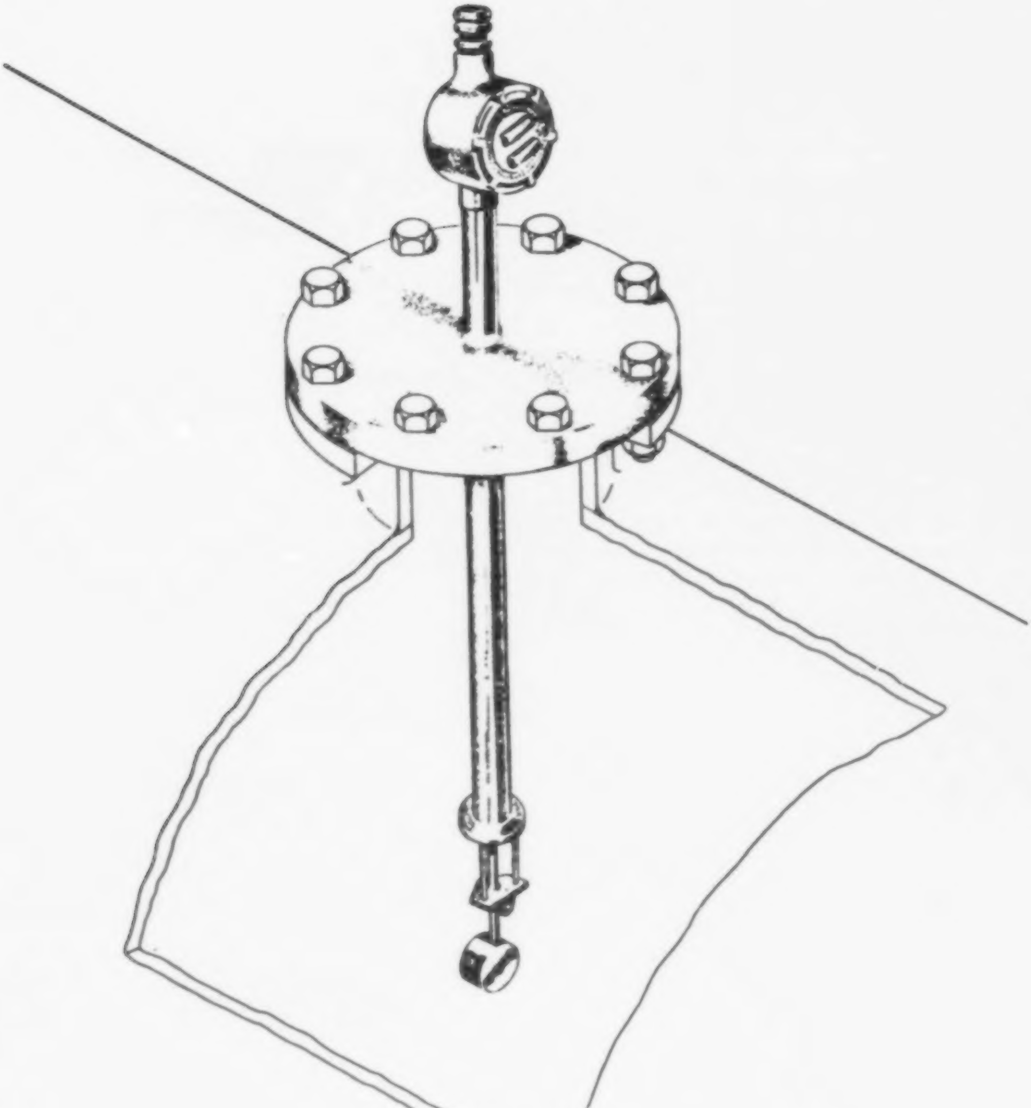

Figure A

Secondary Flowmeasuring Devices - Ramapo markets several recently-developed recorders and digital flowmeters compatible with the Mark V and Mark VI.

One type records flow on an inkless, 5.1 cm (2 in.) wide chart. Signals accepted are typically 0-1 volt or 4-20 mA. The scale and chart use square root ruling so that the flow rate signals originating at target meters, orifices, and other differential pressure devices can be read directly in percent of flow. One chart lasts 30 days. Absolute accuracy is ±2 percent.

Digital-reading flow indicators, with BCD output if desired, are available for reading in engineering units such as GPM, CFM, and ℓ/s. Depending upon the application, the display can present readings to a maximum of 1999, 3999, or 19999.

SPECIFICATIONS:

Line Size*:	10.16 to 152.4 cm (4 to 60 in.)
Calibration*:	±1%; 2%
Accuracy:	±1% full flow (Bi-directional)
Range:	Any 10:1 range up to a line velocity of 4.57 m/s (15 fps) maximum
Materials*:	Stainless steel sensing element; Mounting flange as specified
Pressure Loss*:	Usually less than 10 cm (4 in.) of water
Input:	5 to 10 VDC
Output:	Up to 20 mVDC maximum or 2.0 mVDC input for full range flow rate. Semiconductor gages available for higher output
Connections*:	Terminal strip in explosion-proof enclosure, or submersion-proof head and cable

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* Mark V Flowmeter Probe Only.

PRICES:

Mark V Flowmeter Probes (Standard)

$745 to $1,195 (2% Calibration)

$960 to $2,300 (1% Calibration)

COMMENTS:

Although useful for some types of wastewater flows, these target-type devices do not appear suitable for extended use in the storm or combined sewer application. Their limited range and vulnerability to impact by debris make all but attended, short-time use appear unfeasible.

MANUFACTURER: ROBERTSHAW CONTROLS COMPANY
P.O. BOX 3523
KNOXVILLE, TENNESSEE 37917
TELEPHONE (615) 546-0524

PRODUCT LINE: PARSHALL FLUMES; CAPACITANCE TRANSMITTERS; RECORDERS; INTEGRATORS; TOTALIZERS; ETC.

DESCRIPTION:

Robertshaw markets a variety of analytical and measurement devices, many of which are designed for use with water and wastewater instrument systems. Typical of these is the Series F-Flume Flow Measurement System, which incorporates a circular chart recorder with optional integrator, or a panel-mounted recorder/totalizer.

Flume - The system (Figure A) utilizes as its primary measurement device a Parshall "Free Flow" flume, constructed of polyester reinforced fiberglass with Sanitary Satin finish. The flume is equipped with a molded-in capacitance sensing probe that is characterized to provide a linear output signal directly proportional to flow. The flume is a one-piece, completely self-supporting unit ready for installation in concrete. A ruggedized model may be installed in conduits above the ground. The flume and its associated instrumentation are suitable for many open channel applications.

Transmitter - A capacitance sensing transmitter (Figure A) can be installed directly on the flume probe (Model 157), or mounted in a location remote from the flume. No stilling well is required. Because there are no floats, moving parts, or mechanical linkages, performance is enhanced.

Flow Recorders and Integration/Totalization - Flow recording and integrating/totalization may be provided with the Series F system using the Model 241 circular chart recorder with optional integrator, or the Model 225/534 recorder/totalizer for front panel flush mounting.

The Model 241 electronic circular chart recorder is available in single or two pen versions in a weathertight enclosure for surface or panel mounting. Optional features include built-in integrator-totalizer and/or square-root extractors.

The Model 534 Integrator-Totalizer provides continuous integration and totalization of process signals with respect to time. Ratio adjustment is by means of a long-scale, thumbwheel dial, calibrated for linear or square-root signals. A vertical scale meter displays input/output signals.

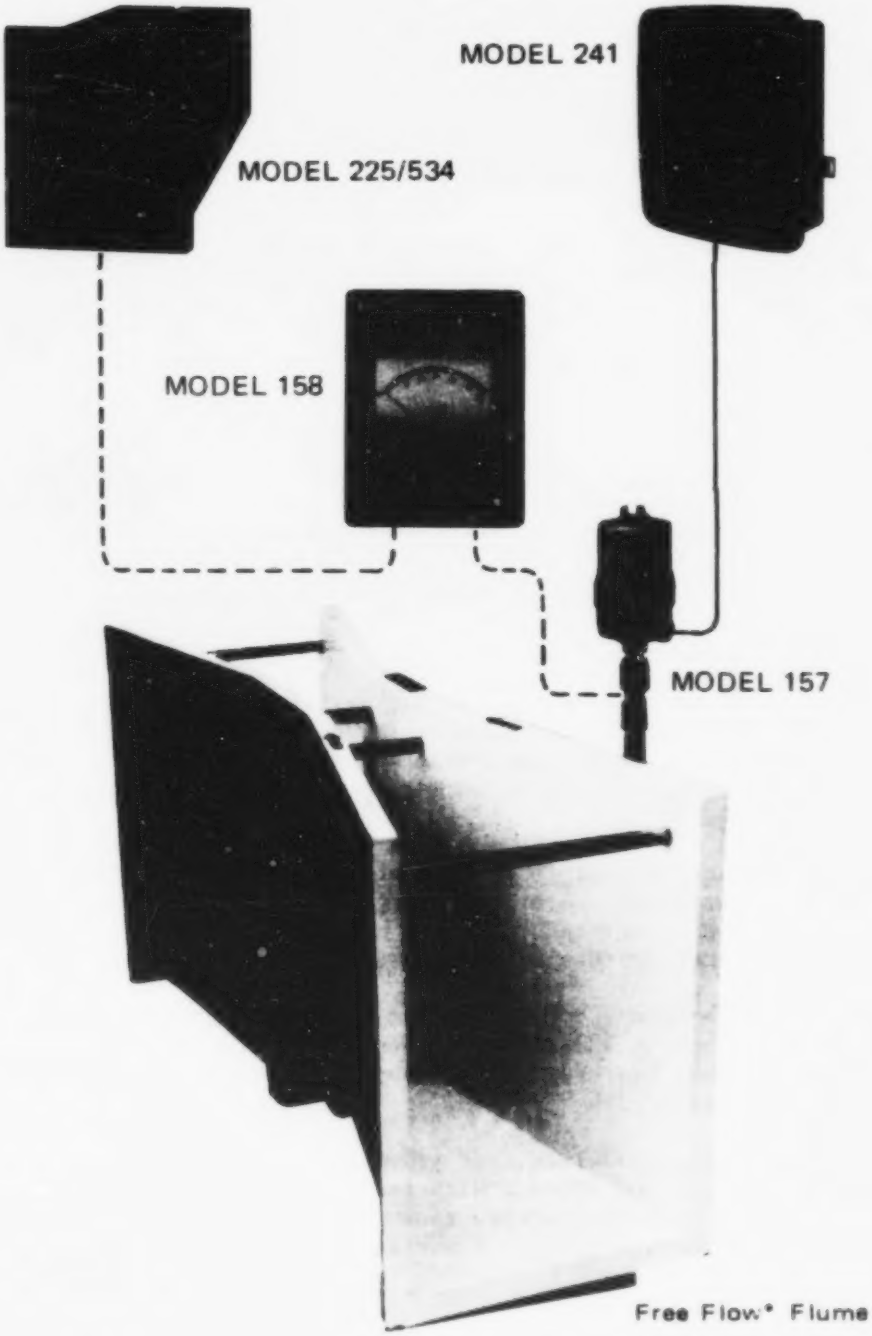

MODEL 241
MODEL 225/534
MODEL 158
MODEL 157
Free Flow® Flume

Figure A

The Models 157/158 Level Tels (transmitters) are capacitance sensing instruments producing standard output current signals and are used for continuous level indication or control.

SPECIFICATIONS:

Model 157/158 Transmitters

Output Signal:	1 to 5, 4 to 20, 10 to 50 mADC
Linearity:	±0.25% of full scale
Repeatability:	±0.1% of full scale
Power:	117/230 VAC or 26 VDC

Model 241 Circular Recorder

Input Signals:	1 to 5, 4 to 20, 10 to 50 mADC
Accuracy:	±1.0% of full scale
Repeatability:	±0.2% of full scale
Pen Response:	2 to 20 sec., adjustable
Power:	117/230 VAC, 50-60 Hz

Model 534 Integrator-Totalizer

Input Signals:	1 to 5, 4 to 20, 10 to 50 mADC
Accuracy:	±0.375% of full scale
Repeatability:	±0.1% of full scale
Count Rate:	1000 to 20,000 CPH
Power:	117/230 VAC or 26 VDC

PRICES:

Not available at time of writing.

COMMENTS:

The capacitance gage molded into the Parshall flume offers advantages for some applications. Parshall flumes were thoroughly discussed in Section VI and will not be commented on further here.

MANUFACTURER: SARATOGA SYSTEMS, INC.
10601 SOUTH SARATOGA-SUNNYVALE ROAD
CUPERTINO, CALIFORNIA 95014
TELEPHONE (408) 257-7120

PRODUCT LINE: ULTRASONIC FLOWMETERS

DESCRIPTION:

Saratoga Systems Inc., under licensing agreement with Lockheed Aircraft Corporation, has patented and is producing the "ULTRAMETER", a frequency difference type "ultrasonic" flowmeter which combines sonar and advanced micro-electronic concepts to measure the flow of any medium capable of providing a uniform flow profile and propagation sound waves in an undistorted manner. This device has a number of applications in the wastewater field.

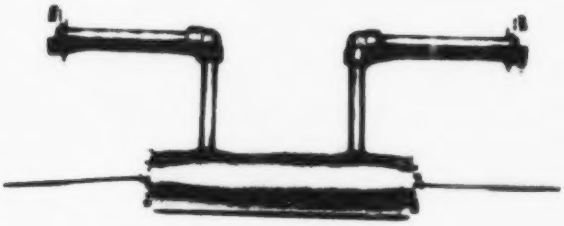
The Model 201 Ultrameter provides either an analog output, or a digital output that is directly proportional to the average speed of a fluid flowing in a pipeline and which can be related to volume flow rate. The measurement system, which employs a pair of non-intrusive diagonally-opposed transducers mounted directly on the pipe itself (see Figure A), is independent of the sound speed in the fluid as well as fluid density, composition, viscosity, and temperature.

Sound "bursts" are propagated alternately in opposite directions between the two transistors. Because the upstream signal is delayed and the downstream signal is speeded up by the moving fluid, the alternate bursts yield a frequency difference which is a highly accurate measurement of the flow (to 0.2%). The measurement also provides linearity even at very low flow rates.

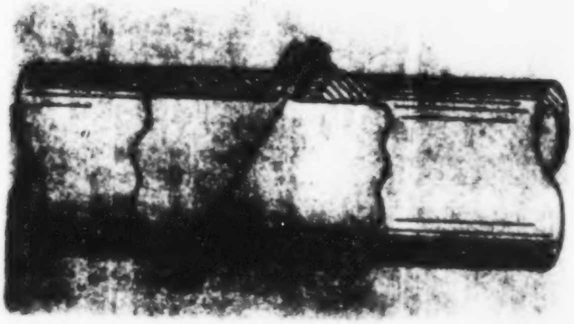
Analog current or digital pulse trains are both simultaneously available from the "ULTRAMETER", and can feed directly to recording and computing equipment. These data signals can be scaled to any desired output dimensions, such as GPM or cubic feet per minute.

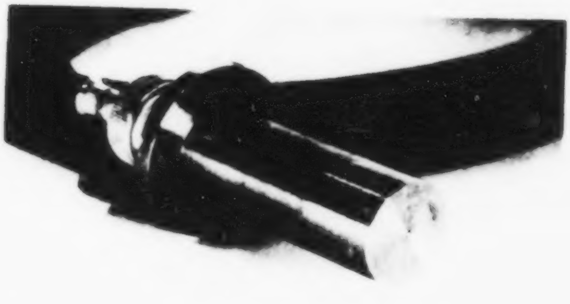
Features include:

- Bi-directional flow measurement capability
- No head loss or obstruction to flow
- No moving parts
- No recalibration after initial factory or inplace calibration



Axial flow section, useful for pipe sizes from ⅛" inside diameter to 3" inside diameter.





Ultrameter transducer receives and emits sound waves.

Figure A

> 100 percent Solid State electronics including replaceable, interchangeable modules and an automatic failure alarm system

The flowmeter may be employed in pipelines ranging from 7.62 cm (3 in.) diameter pipes to open channels.

SPECIFICATIONS:

A typical 9 cm (4 in.) meter flowing 757 ℓ/m (200 gpm) has the following performance and operational characteristics:

Accuracy:	±0.5% (full scale error with calibration)
Resolution:	±0.2% (full scale)
Ranges:	
Upper Flow Limit	100 x Full Scale
Lower Flow Limit	0.1 x Full Scale
Data Format Options:	
Digital	Positive true logic, TTL compatible pulse train proportional to flow.
Analog	0.5% D/A conversion Current Source 0-1, 4-20 or 10-50 mA (Full Scale) Voltage Source ±1 or 0-5 volts (Full Scale)
Power:	117 VAC, 50-60 Hz @ 1 amp
Size:	
Standard Meter Bodies w/ Transducers	0.32 to 46 cm (0.125 to 18 in.)
Weld-on Transducer Installations	10 cm (4 in.) up
Weight:	
Instrument Package	27.2 kg (60 lbs)
Transducers (depending on installation)	42.5 g to 9 kg (1.5 oz to 20 lbs)

PRICE:

Typical price in 20 cm (8 in.) size with remote read-out is $3,680.

COMMENTS:

A large quantity of particulate matter (as can be found in raw or untreated sewage) or heavy concentration of air bubbles can affect the system, although it is reported that up to 50 percent concentrations of solids have been handled. These factors have to be determined in advance consultations with the manufacturer.

There is no restriction on the transducers, but the line has to be full of liquid. The electronic control box can be mounted in any orientation except upside down, but must be within 15m (50 ft) of the transducers. This distance can be extended to 30m (100 ft) under special circumstances.

Overall accuracy of this ultrasonic device depends to a certain degree on the stability and definition of the fluid velocity within the meter path. In some circumstances (e.g., in large diameter pipes and open channels), the flow velocity profile is unstable. Several statistical averaging techniques, such as the Gaussian integration method, can be used with the "ULTRAMETER" to improve accuracy. However, these techniques are complex and involve additional expense.

MANUFACTURER: SCARPA LABORATORIES, INC.
46 LIBERTY STREET, BRAINY BORO STATION
METUCHIN, NEW JERSEY 08840
TELEPHONE (201) 549-4260

PRODUCT LINE: ACTIVE AND PASSIVE ACOUSTIC FLOWMETERS

DESCRIPTION:

Scarpa Laboratories currently manufactures a line of ultrasonic flowmetering and sensing instruments which cover a wide range of liquid and gas applications. Those meters appearing to be best suited for wastewater applications are the non-contacting, clamp-on passive acoustic SFM/SFS Series (2, 3, 4, 5) meters (these are the least expensive) and several more expensive models (e.g., Type II SDL-10, Type IV SDL-8, etc.) that utilize the time difference principle and digital computer technology.

Passive Flowmeters - These clamp-on flow indicators utilize the acoustic emission principal and appear to be usable for liquids, solids, gases, and slurries. All models in this series read relative velocity for liquids and gases and relative mass flow for slurries and solids. The "SCARPA-SONIC" device responds, through a microphone, to broadband noise generated by the moving medium - noises which range from the audible to the high ultrasonic spectrum. Filters are provided to eliminate spurious sounds from sources other than the flowing material. In the cases of liquids and gases, the signal produced is an analog output which is a function of flow velocity; for slurries and powders, it is a function of mass velocity. The sensor element clamps or bonds to the outside of the pipe wall, and the manufacturer states that their best sensing locations are at elbows or flanges. It is further recommended that they should be located at least 3m (10 ft) away, and preferably as far away as possible, from pumps or compressors as they may introduce spurious signals that could pass through the receiver band-pass filters. Very low flow velocities (e.g., slurries) may be sensed by imposing some form of "flow spoiler" in the stream such as an orifice, pipe constrictions, or even any small projection which does not have to have rotational symmetry.

This meter may be used for any pipe size, ranging from 0.31 cm (1/8 in.) O.D. copper tubing to 305 cm (120 in.) or larger pipe diameters. Millivolt, milliampere, and relay contact closure outputs are available. The meter must be calibrated at the site of installation.

Active Flowmeters - The Scarpa active ultrasonic liquid (called "doppler") flowmeter indicates flow by means of two transducers either clamped on the opposite outside walls or inserted through the walls of any pipe size from 7.61 to 152.4 cm (3 to 60 in.). The instrument transmits and receives ultrasonic signals through the pipe wall and across the flow stream at an angle to the flow. The actual measurement is of velocity and is transformed to volumetric flow by means of conversion tables that correct for pipe wall thickness and internal diameter. Units for a specific pipe size can be factory calibrated to read directly in GPM.

Applications range from non-intrusive flow surveys to flow measurement and control where the non-liquid contact feature is essential. The electronics are housed in an industrial grade Nema 4 gasketed box with hinged door.

The doppler type units all employ digital computer technology in processing the information obtained from the ultrasonic "front end." BCD or binary outputs can be provided, as well as 0 to 10 volts, 4 to 20 mA or 10 to 50 mA analog outputs. Digital flow rate displays are also available as standard equipment.

All transducers are metal encased and transmit and receive through resonant metal "windows." As such they can withstand high pressures and most corrosive environments. Materials of construction may be aluminum, titanium, monel or stainless steel. Explosion proof housings are available at additional cost.

SPECIFICATIONS:

Series SF-( ) Flowmeters

Range:	0.3-1.5 m/s (1-5 fps) to sonic velocities*
Accuracy:	Calibrated in place
Reproducibility:	±1%
Power:	117 VAC, 1/10 Amp, 50/60 Hz 9-V Battery Power available some models
Temperature Range:	-40° to + 150°C (Sensor) -40° to + 80°C (Receiver)

Ultrasonic Liquid Doppler Flowmeters (Typical)

Range: (Flow velocity)	0.3 to > 9 m/s (1 to > 30 fps)
Accuracy:	±2%

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* 0-100 μA meter indicates relative flow velocity. May be calibrated on site to indicate actual flow rate.

Repeatability ±2%

PRICES:

SF- Series Flowmeters

SFS-2-RPS	Ultrasonic Clamp-On Flow Switch, with Regulated Power Supply.	$181.50
SFM-3-BP	Ultrasonic Clamp-On Flow Meter, Battery Powered Batteries - $2.75 each extra (2 required)	$330.00
SFM-4-RPS	Ultrasonic Clamp-On Flow Meter, with Regulated Power Supply.	$341.00
SFSM-5-RPS	Flow Switch, Flow Meter Combination with Regulated Power Supply	$467.50
TSL-2-( )	Clamp-On Flow Sensors-Transmitters (Note: At least one TSL-2-( ) sensor is required with each receiver)	$ 93.50 to $165.00

Ultrasonic Liquid Doppler Flowmeters

Type SDL-10	(Clamp on unit)	$3,500-$5,000
Type SDL-8	("Wetted" sensors)	$3,500-$10,000

COMMENTS:

Scarpa offers the only passive acoustic flowmeters on the market today, but little is known about their use in a storm or combined sewer application.

MANUFACTURER: SIGMAMOTOR, INC.
14 ELIZABETH STREET
MIDDLEPORT, NEW YORK 14105
TELEPHONE (716) 735-3616

PRODUCT LINE: BUBBLER-TYPE SECONDARY FLOWMETER

DESCRIPTION:

Sigmamotor has recently introduced their LMS-400 battery operated, open channel flowmeter. It is a bubbler-type secondary device in which a pressure transducer senses the back-pressure experienced by an inert gas which is bubbled at a constant flow rate through a tube anchored at an appropriate point with respect to the primary device (weir, flume, etc.). The flow depth is thus determined and electronically integrated into the appropriate flow equation. Appropriate numeric values for the rest of the flow equation are set with two dials on the front of the meter.

The device appears to be extremely simple to set up and put into operation. It can operate up to 122m (400 ft) from the measurement site. This unit, which is claimed to be one of the smallest and most accurate flowmeters available, is equipped with a 31-day pressure sensitive strip chart recorder for a continuous record of flow rate and a six digit totalizer reading in gallons to indicate total flow over time. Besides the flow rate readouts in CFS or MGD, the LMS-400 can be set to simply give depth readouts in either feet or inches. It is also designed to supply a flow-proportional signal for an automatic sampler and will indicate at what time each individual aliquot was taken.

SPECIFICATIONS:

Accuracy:	±2% from the theory curve of the primary device
Power:	AC units, 115V DC units, 12V Lead Acid Type Battery
Battery Life:	30 Amp-Hour - 10 days 15 Amp-Hour - 5 days
Bubbler Cylinders:	0.9 kg (2 lb) Freon R-12 gas cylinders (two) last for approximately 3 to 4 weeks
Dimensions:	34.3x36.8x25.4 cm (13.5x14.5x10 in.)
Weight:	15.9 kg (35 lb) with 30 Amp-Hour Battery 11.8 kg (26 lb) with 15 Amp-Hour Battery 8.2 kg (18 lb) AC model

PRICES: $1,750 for AC-DC Unit

COMMENTS:

This small, versatile unit appears to be well suited, in conjunction with appropriate primary devices (linear, 3/2 or 5/2 power), for many wastewater flow surveys. Its complete portability makes it especially attractive for such use. Wide range requirements could pose a problem; although the unit has four range settings, they must be set manually.

MANUFACTURER: SINGER-AMERICAN METER DIVISION
13500 PHILMONT AVENUE
PHILADELPHIA, PENNSYLVANIA 19116
TELEPHONE (215) 673-2100

PRODUCT LINE: PARSHALL AND PALMER-BOWLUS FLUMES; LIQUID LEVEL GAGES

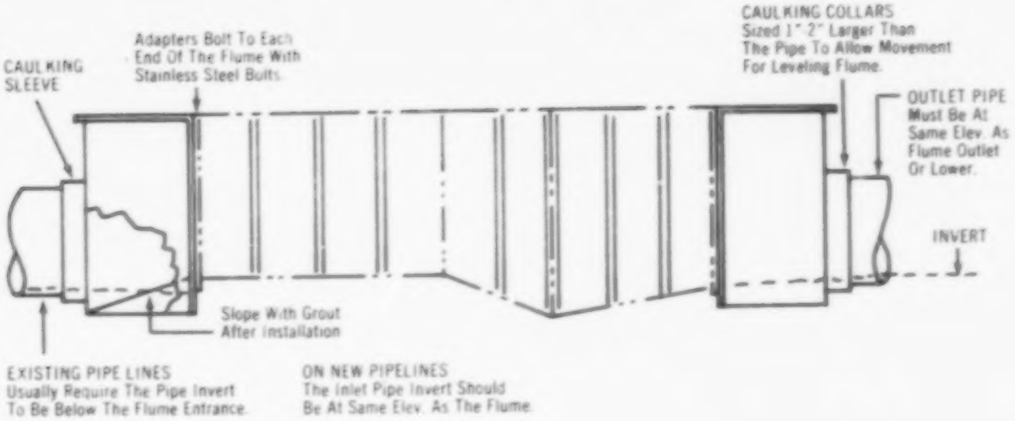
DESCRIPTION:

The American Meter Division of Singer offers Parshall flumes in sizes from 7.6 to 30.5 cm (3 to 12 in.) as standard and up to 2.4m (8 ft) on special order. The flumes are heavily ribbed for free-standing installations and may also be used as liners in concrete. They are fabricated in one piece from polyester plastic resin, reinforced by glass mat not less than 30 percent by weight, and have a smooth white surface. A connection is available on either side for a bubbler pipe, and a head gage is molded into the side of the flume. For installation in pipelines, American also offers Parshall flume end adaptors to make the transition from round pipe to rectangular flume and back to round (Figure A). Short-section flumes (i.e., no diverging section), are available for use where space is restricted and the additional head loss is tolerable.

The Palmer-Bowlus flumes offered by American feature a trapezoidal section with a flat bottom. Recommended installation techniques include grouting or adhesive bonding. They are also molded from fiberglass-reinforced isophthalic polyester resin with a white gel coat interior surface. The outside surface has clips for anchoring to concrete. The flume includes a built-in stainless steel bubbler tube.

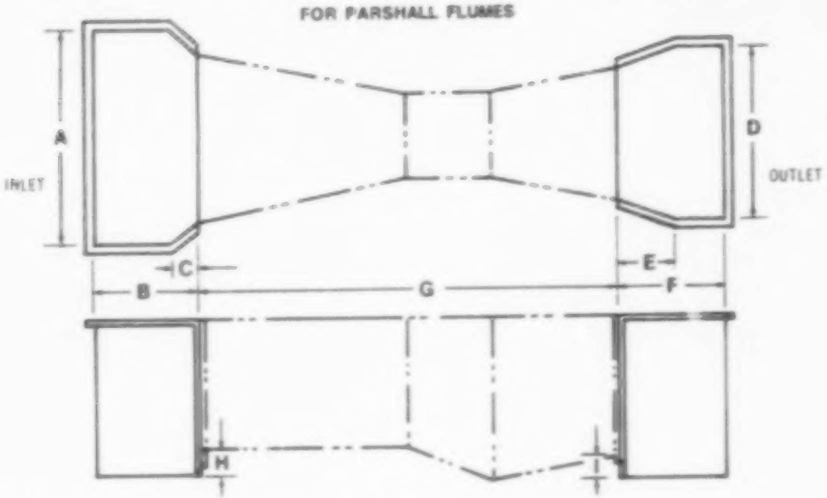
American offers a number of secondary elements (Figure B) for use with V-notch weirs, rectangular weirs, Parshall flumes, and Palmer-Bowlus flumes. Spring-wound, battery, or electrical (110 VAC) chart drive speeds can be either 24 hours or 7 days per revolution. Integrating instruments use electrical drive charts.

The American bubbler tube level system utilizes an air pump to pressurize a capsular pressure element. A tee is incorporated in the line leading to the capsular pressure element to bleed off a continuous flow of air (back pressure at the capsular pressure element) to the dip tube. The dip tube is open at one end and submerged, for example in a weir with the open end on a plane with the bottom of the weir notch. The air escaping from the open end of the dip tube produces bubbles (air pump is adjusted to produce approximately 30 to 90 bubbles per minute); thus, the air pressure in the dip tube corresponds to the hydraulic head of the liquid. As the liquid head varies, the pressure in the tube changes. This tube pressure is proportional to the pressure variation at the capsular pressure element. Here the movement of the capsular pressure element is transmitted to an integrating stylus and recording pen arm which accurately records a pattern of liquid flow. The integrating instrument totalizes the actual volume measured. The integrating mechanism is a rotating cylindrical cam with a surface corresponding to the weir notch characteristic. Depending upon the position of the pressure stylus, the cam actuates the counter drive for a portion of each revolution. Since all functions are performed by special gearing, there are no clutches to cause backlash or slippage.


CAULKING SLEEVE
Adapters Bolt To Each End Of The Flume With Stainless Steel Bolts.
CAULKING COLLARS Sized 1"-2" Larger Than The Pipe To Allow Movement For Leveling Flume.
OUTLET PIPE Must Be At Same Elev. As Flume Outlet Or Lower.
INVERT
Slope With Grout After Installation
EXISTING PIPE LINES Usually Require The Pipe Invert To Be Below The Flume Entrance.
ON NEW PIPELINES The Inlet Pipe Invert Should Be At Same Elev. As The Flume.

STANDARD INLET AND OUTLET ADAPTERS

FOR PARSHALL FLUMES


A
INLET
D
OUTLET
C
E
B
G
F
H

End Connections, such as caulking collars, are not shown as size and type may vary.

FLUME SIZE	A	B	C	D	E	F	G	H	I
3"	1'-6"	12"	9"	1'-6"	9"	12"	3'-0"	5"	6"
6"	2'-0"	1'-6"	7"	2'-0"	7"	1'-6"	5'-0"	6"	3"
9"	2'-8"	1'-9"	8"	2'-0"	8"	1'-9"	5'-4"	6"	4"
12"	3'-9"	2'-0"	10"	2'-9"	8"	2'-0"	9'-4⅛"	7"	4"
18"	4'-4"	2'-0"	10"	3'-4"	8"	2'-0"	9'-7⅜"	8"	5"
24"	5'-0"	2'-6"	7"	4'-8"	1'-4"	2'-6"	9'-10⅝"	8"	5"

Figure A

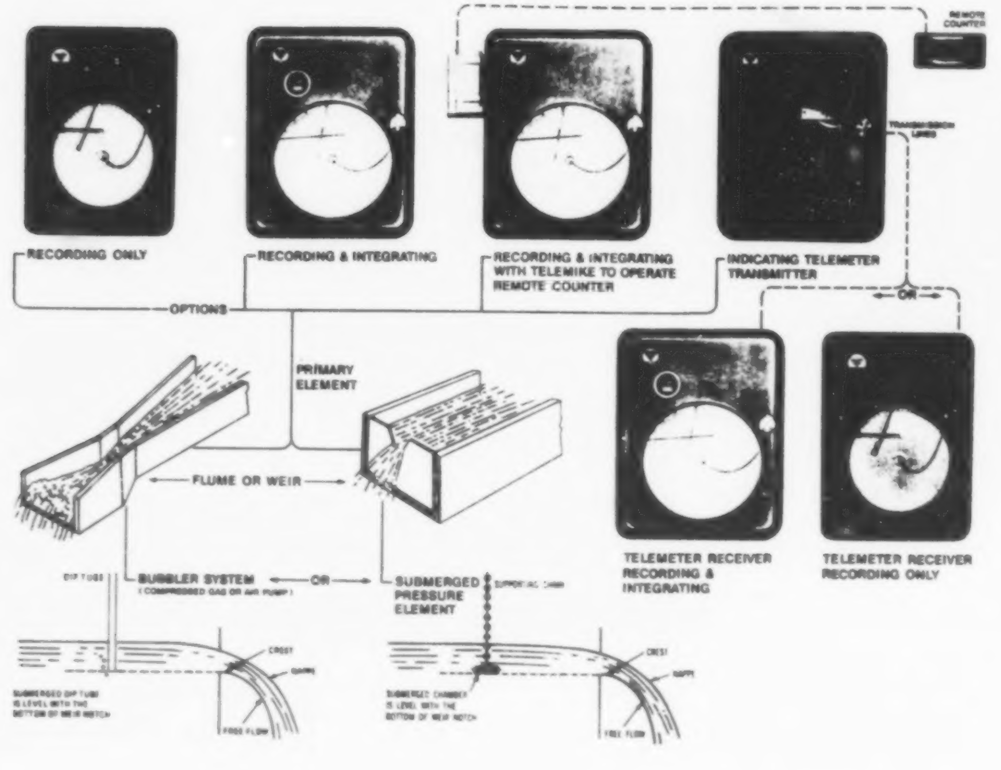

REMOTE COUNTER
TRANSMISSION LINES
RECORDING ONLY
RECORDING & INTEGRATING
RECORDING & INTEGRATING WITH TELEMIKE TO OPERATE REMOTE COUNTER
INDICATING TELEMETER TRANSMITTER
OPTIONS
OR
PRIMARY ELEMENT
FLUME OR WEIR
TELEMETER RECEIVER RECORDING & INTEGRATING
TELEMETER RECEIVER RECORDING ONLY
DIP TUBE
BUBBLER SYSTEM
(COMPRESSED GAS OR AIR PUMP)
OR
SUBMERGED PRESSURE ELEMENT
SUPPORTING CHAIN
CREST
NAPPE
SUBMERGED DIP TUBE IS LEVEL WITH THE BOTTOM OF WEIR NOTCH
FREE FLOW
SUBMERGED CHAMBER IS LEVEL WITH THE BOTTOM OF WEIR NOTCH
CREST
NAPPE
FREE FLOW

Figure B

MANUFACTURER: SPARLING DIVISION
ENVIRONTECH CORPORATION
4097 NO. TEMPLE CITY BLVD.
EL MONTE, CALIFORNIA 91731
TELEPHONE (213) 444-0571

PRODUCT LINE: PROPELLER FLOWMETERS; TRANSMITTERS, RECORDERS, AND INDICATORS/TOTALIZERS

DESCRIPTION:

Sparling Manufactures a variety of propeller-type meters, electromechanical devices and controls, solid state instruments, and telemetering equipment. Some of these are suitable, or are potentially acceptable, for some wastewater and/or sewer flow applications. Of particular interest are the Series 100 meters (Masterflow wastewater meters) and a variety of electrical flow rate transmitters for use with flumes or weirs or for mounting on meterheads to operate remote recorders, indicators, and/or totalizers.

Sparling offers two styles of wastewater meters - the flanged Masterflow tube type and the Masterflow Open Flow type (see Figure A). For both models, application in measuring waste flows is recommended only after primary treatment, including waste or return activated sludge. These meters are not recommended for raw sewage or primary sludge flows. Therefore they will not be described further.

Secondary Measurement Devices - Secondary devices offered by Sparling include the following:

- Pulse-Rate Transmitters - These designs utilize an optical pulse-rate generator to provide a 0 to 20 PPS signal directly proportional to flow rate.
- Electronic Transmitters - Measure and transmit level, pressure, or other variables. Output signal accuracy is ±1%. Pulse frequency, DC voltage, or current output modes.
- Miniature Strip-Chart Recorders - Indicate and continuously record flow, pressure, level, or other variables. Can accommodate solid state or relay-contact output switches for alarm, status indication, etc.
- Circular-Chart Recorders - Feature 30.4 cm (12 in.) linear charts designed for either 24-hour or 7-day recording; 25.4 cm (10 in.) indicator scale; and six-digit direct-reading totalizer.

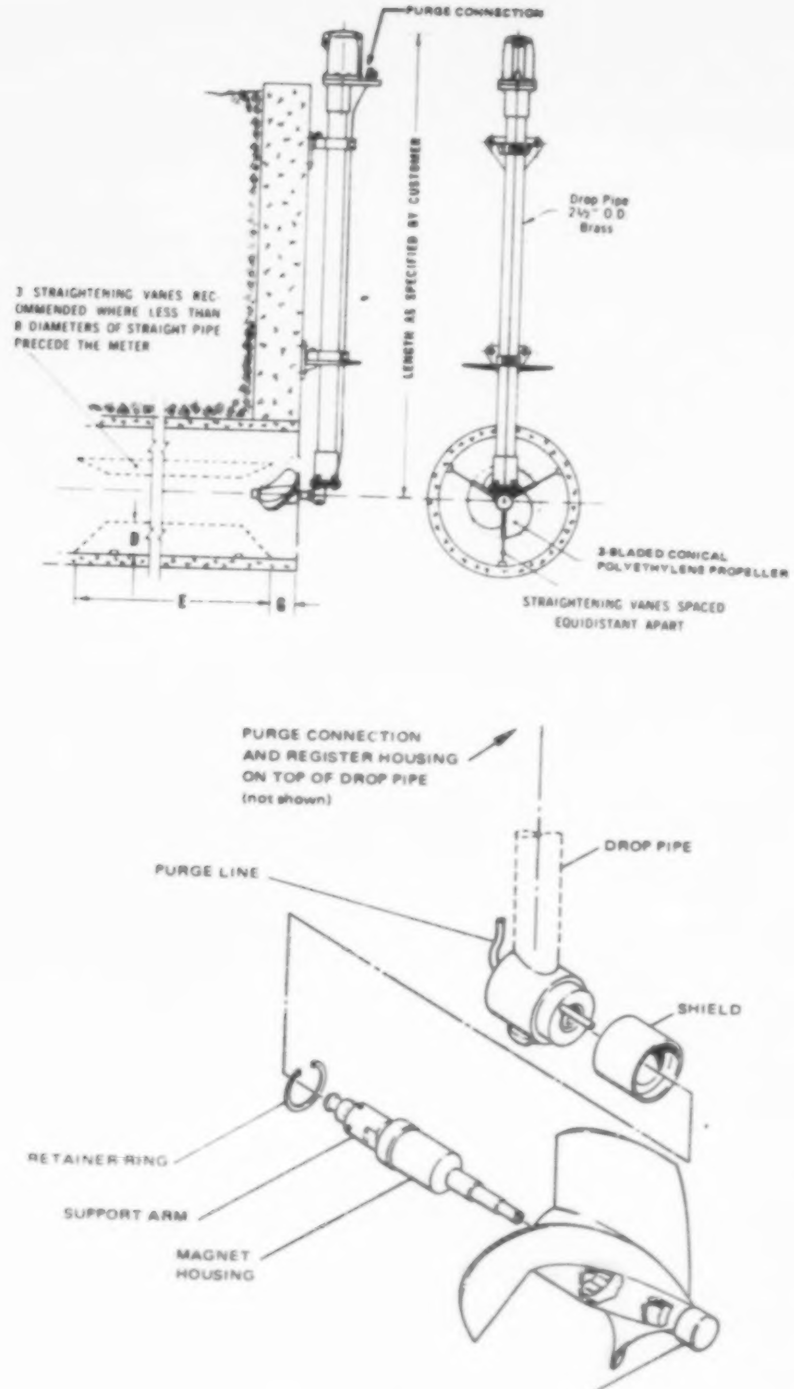

PURGE CONNECTION
LENGTH AS SPECIFIED BY CUSTOMER
Drop Pipe
2½" O.D
Brass
3 STRAIGHTENING VANES REC-
OMMENDED WHERE LESS THAN
8 DIAMETERS OF STRAIGHT PIPE
PRECEDE THE METER
D
E
G
3-BLADED CONICAL
POLYETHYLENE PROPELLER
STRAIGHTENING VANES SPACED
EQUIDISTANT APART
PURGE CONNECTION
AND REGISTER HOUSING
ON TOP OF DROP PIPE
(not shown)
DROP PIPE
PURGE LINE
SHIELD
RETAINER RING
SUPPORT ARM
MAGNET
HOUSING
PROPELLER CAP

Figure A

COMMENTS:

Propeller meters are not recommended by Sparling for use in raw sewage and are unsuitable for a storm or combined sewer application.

MANUFACTURER: TAYLOR
SYBRON CORPORATION
TAYLOR INSTRUMENT PROCESS CONTROL DIVISION
TELEPHONE (716) 235-5000

PRODUCT LINE: ELECTROMAGNETIC FLOWMETERS, SUBMERSIBLE PROBES

DESCRIPTION:

Flowmeters - The "MAG-PIPE" 1100/1200 Series electromagnetic flowmeters measure flow by Faraday's Law of Magnetic Induction. A low-level, AC signal generated by the movement of a conductive fluid in a magnetic field is amplified by a solid-state transmitter which may be used directly with Taylor receiving instruments such as controllers, recorders, integrators, etc. Figure A shows a typical installation.

The 1100T or 1101T transmitters are used with Taylor 1100L, 1101L, 1200L, 1210L, 1211L, 1240L, and 1241L sensing heads. The 1100T is the remote unit and can be mounted up to 366 meters (1200 feet) from the sensing head. The 1101T is the integral form and is mounted directly on the sensing head; it produces a 4 to 20 mA DC signal which is linear with flow. The transmitters are completely solid state and incorporate thick film hybrid integrated circuits and an automatic quadrature rejection (or null adjustment) feature which eliminates costly and time-consuming start-up. If pneumatic output is required, the 1100L can be coupled to a Taylor 737 transmitter. Teflon is the standard liner material used in the "MAG-PIPE" 1100L sensing head, although a variety of other liner materials are offered.

The recently introduced Taylor 1210L series uses self-cleaning electrodes to eliminate the measurement problems caused by severe coating buildup. The electrode material used is Carpenter 20cb-3 stainless steel, which is ceramic coated for this application. Only a conductive "eye" (Figure B) for signal pickup is untreated; the eye protrudes into the higher velocity portion of the process stream which is said to have a cleansing action on the eye caused by the eye's unique geometric construction.

Submersible Probes - Taylor also manufactures a submersible probe for measuring flow in large process pipes of 50.8 cm (20 in.) I.D. or over. The probe is a 15.24 cm (6 in.) magnetic flowmeter consisting of platinum foil electrodes fired into a ceramic tube. The probe can be used with either a remote or integrally mounted transmitter. The assembly is welded to a mast which is fastened to a flange. When inserted into the process piping, the ±2% accuracies may be achieved when a symmetrical velocity profile exists at velocities above 0.6 m/s (2 fps). In addition, compensation can be made for non-symmetrical velocity profiles by field calibration techniques such as pitot traverses, dye dilution, or other acceptable methods.

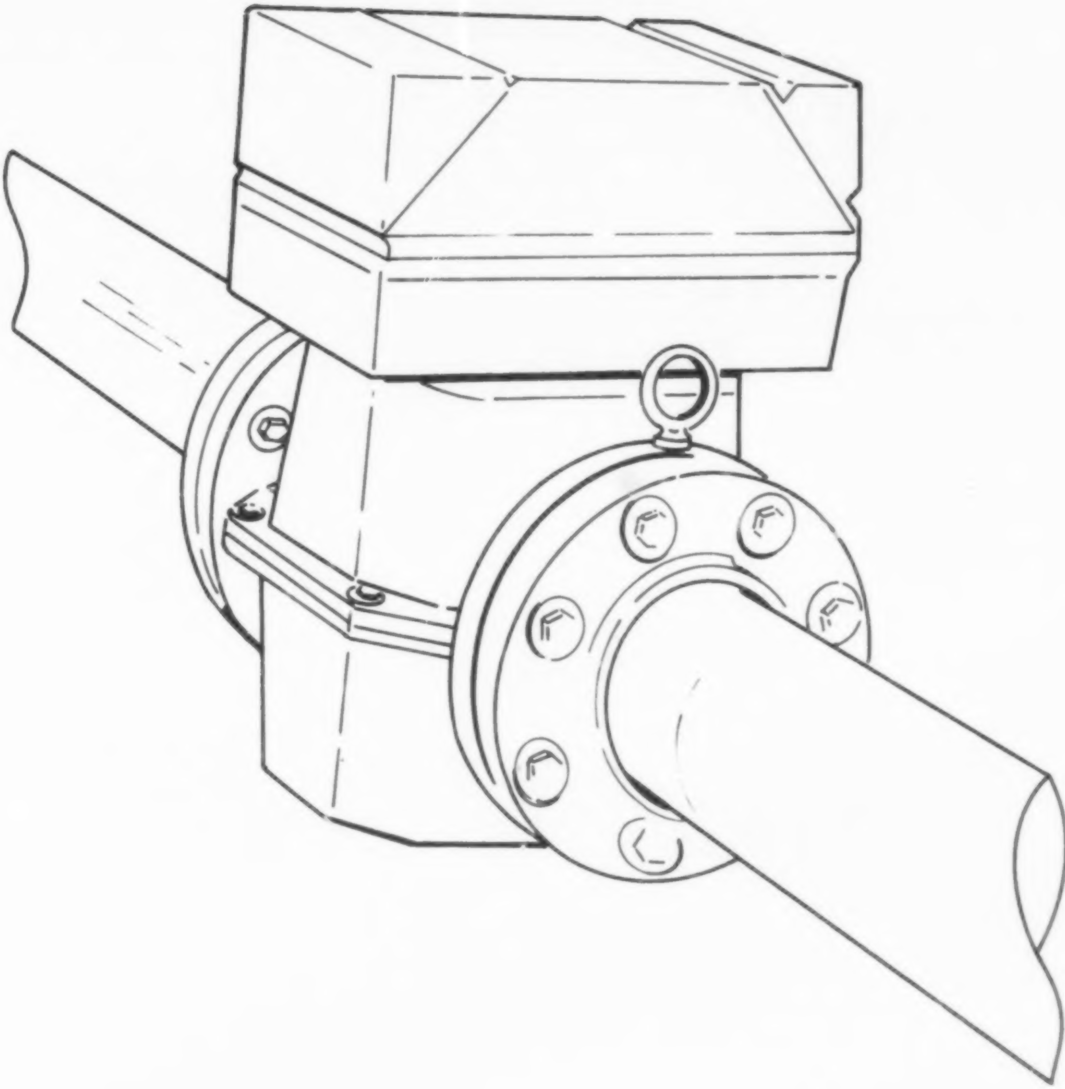
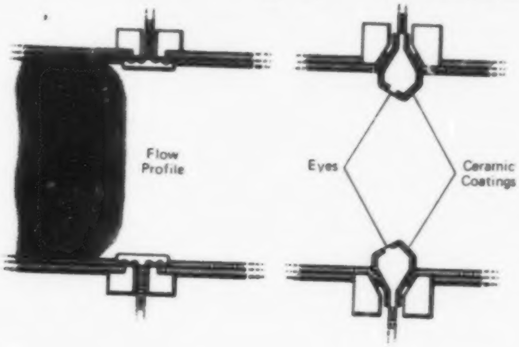


Figure A

Self-Cleaning Electrodes


Flow Profile
Eyes
Ceramic Coatings

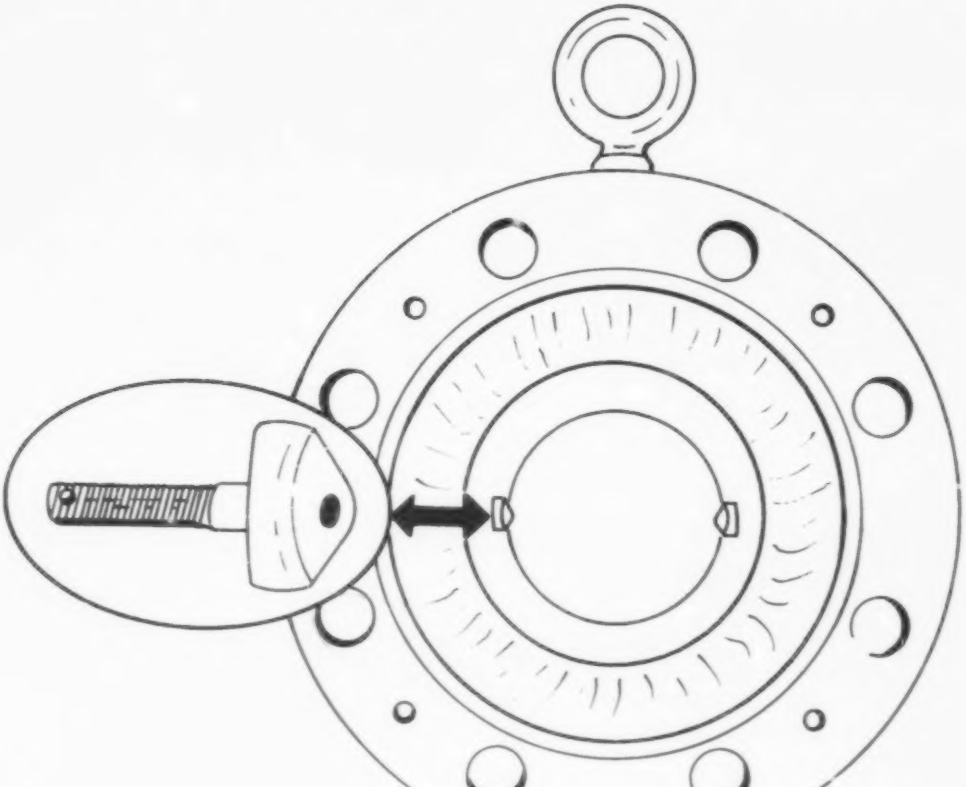


Figure B

SPECIFICATIONS:

1100/1200 Series Flowmeters (Typical)

Accuracy (including Sensing Head and Transmitter):	±1% of flow (Sensing Head and Transmitter calibrated separately) ±0.5% of flow (Integral Mounting or Sensing Head and Transmitter calibrated together) ±0.25% of flow between 0.91 and 4.57 m/s (3 and 15 FPS) (optimum calibration)
Repeatability (including Sensing Head and Transmitter:	±0.2% of flow
Flow Range:	0-0.9 to 0-9.0 m/s (0-3 to 0-30 fps)
Sensitivity (Approx)*:	300 microvolts rms/ft/sec
Output Signal**:	4-20 mA, DC
Minimum Process Conductivity:	Down to 1 micromho/cm
Power:	117 VAC, 50/60 Hz or 117 VAC/234 VAC, 50 Hz
Power Consumption**:	12 VA, 11.8 watts
Pipe Sizes:	2.54 cm (1 in.) to 30.48 cm (12 in.)
Weight:	6 kg (13 lb) - Transmitter; 20.4 kg (45 lb) to 109.0 kg (240 lg) - Sensing Head

PRICES: Sensing Heads, from $935.00 to approximately $5,000 (MAG-PIPE 1100 Series only)

Transmitters, Remote Mounted -- $810.00

Transmitters, Integrally Mounted on Sensing Head -- $791.00

COMMENTS:

The Taylor line of electromagnetic flowmeters features a number of what are claimed to be unique features that extend the utility of their devices. Electromagnetic flowmeters were discussed thoroughly in Section VI and will not be discussed further here.

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* Sensing Head only

** Transmitter only

MANUFACTURER: THERMAL INSTRUMENT COMPANY
41 TERRY DRIVE
TREVOSE, PENNSYLVANIA 19047
TELEPHONE (215) 355-8400

PRODUCT LINE: THERMAL FLOWMETERS AND FLOW PROBES

DESCRIPTION:

The Thermal Instrument Company offers the Model 60 and 60-L thermal flowmeters which could be applicable to the measurement of combined sewage and stormwater; however, their Model 62-L thermal mass flow probe and thermal flow probe (no model number) do not appear to be suitable for this application because of the vulnerability of such probes to damage when inserted in effluent and stormwater flows having large quantities of suspended materials.

Model 60 Thermal Flowmeter - This device consists of a single, unobstructed flow tube having no moving parts. The meter utilizes the thermal boundary layer principle in which the sensing elements (i.e., temperature and flow) are located on the outer surface of the tube and never contact the flowing medium. The flow sensor is energized with a small amount of electrical energy (less than one watt); the heat conducted off this element, by the flow stream, is directly proportional to the mass flow rate of the fluid. Additional sensing elements are located on the tube to compensate and correct for the effects of fluid and ambient temperature. It is reported that any fluid can be metered, no matter how corrosive or abrasive. The meter is said to be not attitude sensitive and therefore can be mounted vertically to prevent the buildup of solid particles in slurries. The meter can be used with a variety of standard potentiometric recorder or control devices, standard industrial and military tranrducers, and digital readouts.

Model 60-L Thermal Flowmeter - The Model 60-L is a "spool piece" type meter and is similar to the Model 60 in basic operation, with one fundamental difference. The Model 60-L also has acquired level sensors on the outside diameter of the flow tube. Figure A is a diagram showing the location of the level and velocity elements in this combination meter body. The product of the readouts provided by the velocity and liquid level measuring sensors will give total instantaneous flow in a partially filled effluent duct, which usually is so designed that it will never operate completely full except under emergency conditions.

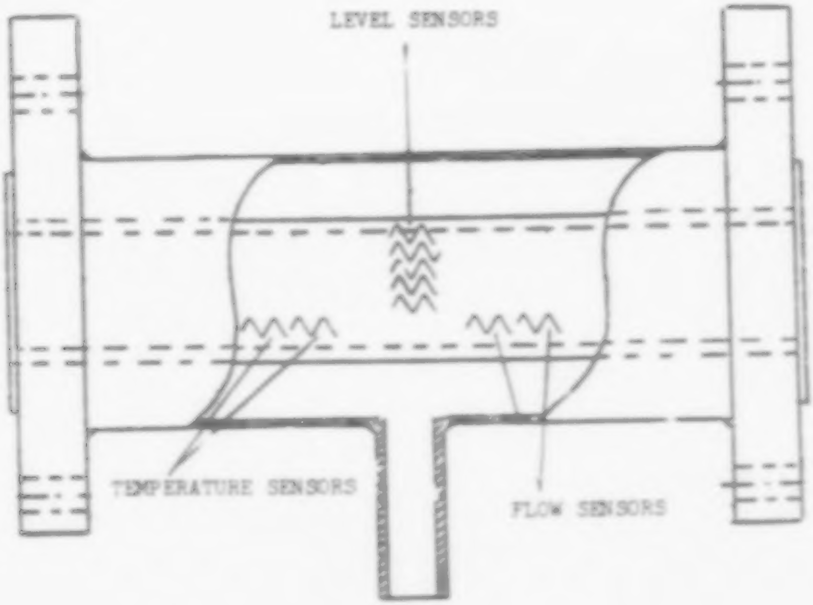


Figure A

SPECIFICATIONS:

Model 60 Thermal Flowmeter

Output:	0 to 10 mVDC signal to operate any standard potentiometric recorder or control device (standard) 1 to 5, 4 to 20, 10 to 50 mA or 1 to 5 VDC for recording and control purposes (optional) 3 to 15 psig or 3 to 30 psig pneumatic signals (optional) Digital readout with BCD (optional)
Flow Rate:	1 cc/min. (minimum); no upper limit
Accuracy:	±1%
Repeatability:	> ±0.2% of reading
Response Time:	1/2 sec.
Pipe Sizes:	up to 50.8 cm (20 in.)
Power:	115 VAC, 60 Hz, < 20 watts

Model 60-L Thermal Flowmeter

Accuracy:	Velocity - 1%
	Level - 1%
	Overall - 2%

Other attributes are similar to Model 60.

PRICE:

Prices vary with size and particular specification details; a complete Model 60-L in a 61 cm (24 in.) size costs around $15,000.

COMMENTS:

The Thermal Instrument Company's products appear very suitable for measuring storm and combined sewer flows if all the manufacturer's claims are valid. No applications data on these fairly new devices are available for such services.

MANUFACTURER: TRI-AID SCIENCES, INC.
161 NORRIS DRIVE
ROCHESTER, NEW YORK 14610
TELEPHONE (716) 461-1660

PRODUCT LINE: ULTRASONIC FLOWMETER

DESCRIPTION:

The Tri-Aid Sciences temperature-compensating, ultrasonic flow measurement and transmitter system is designed for use with open channel flumes or weirs having a 3/2 power flow characteristics. The model FC-3-SW ultrasonic transmitter, when correctly installed and calibrated, will measure the water depth in front of the flume or weir.

This system consists of two basic components. The first is an enclosure housing the electronic control, integrated circuit flow characterizer, and transmitter. The second is an ultrasonic transducer "head" for bracket mounting above the water flow at the flume or weir. The transmitter and "head" are connected with a coaxial cable for the measuring signal and two wires for air temperature compensation. The system generates a high frequency sound pulse from the "head" mounted above the water flow. When the sonic pulse is reflected from the water's surface and received back, the control interprets the time delay period into water depth and the integrated circuit function module characterizes the signal into a linear 4 to 20 MADC flow signal output.

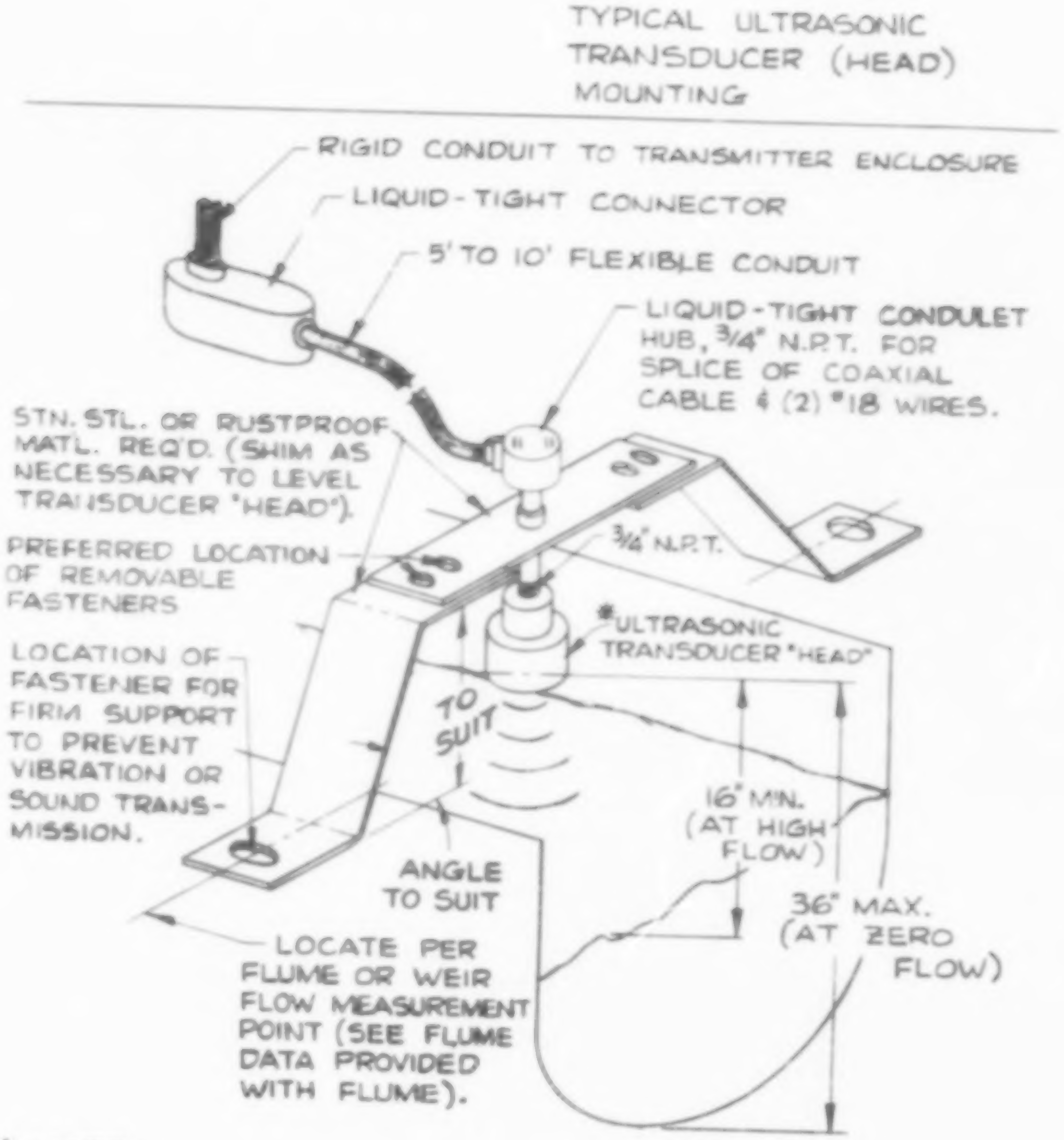
The transmitter is enclosed in a 40.6 X 35.6 X 15.2 cm (16X14X6 in.) oil- and dust-tight fiberglass enclosure for wall mounting. The explosion-proof "head" is encapsulated in Kynar to protect it from the effects of liquids and most industrial operating environments. The output signal from the FC-3-SW may be used to provide a remote input to a Tri-Aid integrator system for flow totalizing and sampling control. It may also be used with indicators, recorders, controllers, and/or computers to meet the customer's system requirements. The transmitter enclosure can be located up to 91m (300 ft) from the weir or flume. Typical installation details are shown in Figure A. Power requirements for the system are: 115 VAC, single phase, 10 amps, 60 Hz ±10%.

PRICE:

Not available at time of writing.

COMMENTS:

The 0.9m (3 ft) maximum distance from the face of the transducer head to the zero flow datum is for standard calibration. For special applications, this distance can be increased up to 6m (20 ft) to meet requirements for many storm or combined sewer applications.


TYPICAL ULTRASONIC TRANSDUCER (HEAD) MOUNTING
RIGID CONDUIT TO TRANSMITTER ENCLOSURE
LIQUID-TIGHT CONNECTOR
5' TO 10' FLEXIBLE CONDUIT
LIQUID-TIGHT CONDULET HUB, 3/4" N.P.T. FOR SPLICE OF COAXIAL CABLE & (2) #18 WIRES.
STN. STL. OR RUSTPROOF MATL. REQ'D. (SHIM AS NECESSARY TO LEVEL TRANSDUCER 'HEAD').
PREFERRED LOCATION OF REMOVABLE FASTENERS
3/4" N.P.T.
*ULTRASONIC TRANSDUCER "HEAD"
LOCATION OF FASTENER FOR FIRM SUPPORT TO PREVENT VIBRATION OR SOUND TRANSMISSION.
TO SUIT
16" MIN. (AT HIGH FLOW)
36" MAX. (AT ZERO FLOW)
ANGLE TO SUIT
LOCATE PER FLUME OR WEIR FLOW MEASUREMENT POINT (SEE FLUME DATA PROVIDED WITH FLUME).

* NOTE:
BOTTOM SURFACE OF TRANSDUCER 'HEAD' **MUST** BE PARALLEL TO LIQUID SURFACE.

Figure A

MANUFACTURER: UNIVERSAL ENGINEERED SYSTEMS, INC.
7071 COMMERCE CIRCLE
PLEASANTON, CALIFORNIA 94566
TELEPHONE (415) 462-1543

PRODUCT LINE: FLOWMETERING SYSTEMS (CONTROL CABINET, RECORDER, TOTALIZER, READOUTS)

DESCRIPTION:

UES offers its electronic FLO/Monitor flow measurement system in several different configurations - i.e., for permanent installations, remote or temporary locations, and intrinsically safe installations for "hazardous" area applications. Specifically designed for measuring wastewater flow in manholes, in effluent and influent lines, etc., this completely electronic system, which utilizes a Palmer-Bowlus flume for its primary element, does not employ floats, probes, mechanical linkages, or bubblers. The basic unit consists of a control cabinet and the measuring flume. The control cabinet contains the electronic circuits, flow recorder, flow totalizer, power supply, etc. The measuring flume carries an embedded sensor element which provides the electronic information relating water depth to flow. Figure A shows a typical temporary manhole installation.

Measuring Flume - The physical configuration and dimensions of this primary measuring device (Figure B) follow the standard Palmer-Bowlus concepts. Its smooth, acrylic-PVC plastic construction is rugged and causes little, if any, disturbance or restriction to water flow. Sizes to 30.5 cm (12 in.) are stock items; larger sizes may be obtained by special order.

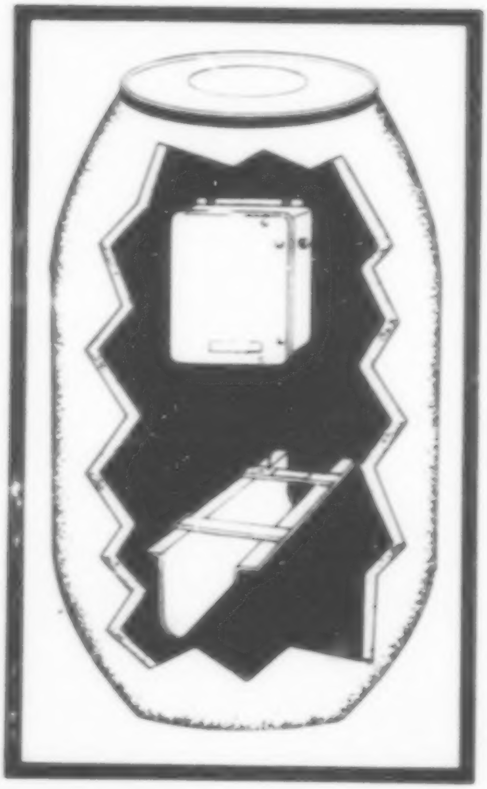
Flow Rate Recorder - This secondary device provides a 30-day, continuous strip chart for recording a permanent record of flow variations (rate vs time) in the sensing flume at all times. Special pressure-sensitive chart paper is used.

Flow Totalizer - This six-digit counter displays total flow volume through the flume in units from one thousand to one billion gallons.

Telemetering - Via a special operational plug provided with each monitor, flow rate and total flow information can be sent to central office terminals. Built-in logic circuits are provided for this purpose.

Remote Display - Up to 1525m (5000 ft) of 6-conductor, No. 20 gauge shielded wire can be provided as interconnecting cable between an optional remote display and the low-voltage FLO/Monitor computer (Model 8092 only). The remote display contains a flow rate recorder and a flow totalizer and an alarm to signal excessively high or low flow rate.

Temporary Location
Model 8091



Permanent Installation
Model 8090

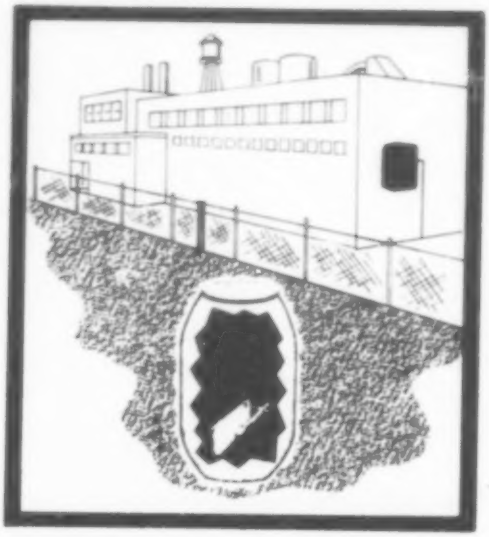


Figure A

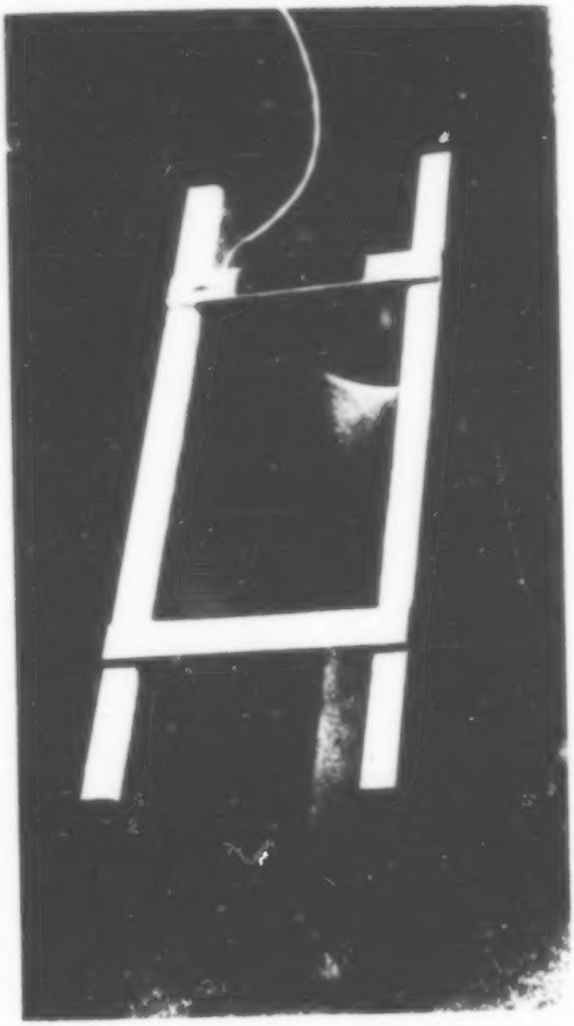


Figure B

SPECIFICATIONS:

Flume

Pipe Size - cm (in.)	Length - cm (in.)	Max Flow - MLPD (MGD)
10.2(4)	26.4(14)	.475(.125)
15.2(6)	50.8(20)	.95(.25)
20.3(8)	68.6(27)	1.90(.50)
25.4(10)	81.3(32)	3.42(.90)
30.5(12)	96.5(38)	5.32(1.40)

FLO/Monitor (All Models unless otherwise indicated)

Accuracy:	±4% full scale
Power:	120V 60 Hz 12V (Rechargeable gel-battery for 8091 FLO/Monitor)
Size:	
Control Cabinet	30.4x35.6x15.2 cm (12x14x6 in.)
Remote Display Unit (8092 only)	20.3x25.4x10.2 cm (8x10x4 in.)
FLO/Computer (8092 only)	20.3x25.4x10.2 cm (8x10x4 in.)
Weight:	
Control Cabinet (8090/8091)	9.07 kg (20 lb)
Power Supply (8091 only)	11.34 kg (25 lb)
Remote Display Unit (8092 only)	~4.54 kg (~10 lb)
FLO/Computer (8092 only)	~2.27 kg (~5 lb)
Temperature Range:	-1° to +49°C (30° to 120°F)
Price:	Not available at time of writing.

COMMENTS:

Using a characterized electronic probe embedded in the wall of the Palmer-Bowlus flume offers many advantages for storm or combined sewer application. However, the one-piece design will present size restrictions due to manhole entry dimensions.

MANUFACTURER: VICKERY-SIMMS, INC.
P.O. BOX 459
ARLINGTON, TEXAS 76010
TELEPHONE (817) 261-4446

PRODUCT LINE: ORIFICE PLATES, FLANGES, FITTINGS, AND METERING TUBES; ASME AND SHORT-FORM VENTURI TUBES; FLOW NOZZLES; PARSHALL FLUMES; TURBINE FLOWMETERS

DESCRIPTION:

Vickery-Simms is a long-established manufacturer of primary flow measurement devices. Each of their product lines will be discussed briefly.

Orifice Plates and Accessories - Vickery-Simms (VSI) maintains an environmentally-controlled atmosphere where concentric, eccentric, segmental, and quadrant edge orifice plates are bored to precision tolerances in conformance with AGA, ISA, and ASME recommendations (unless otherwise specified by the customer). Each plate is stamped with line size, ASA rating, material, and exact orifice bore. All plates which are beveled are stamped "inlet" on the square-edged side.

Sizes available for line diameters are from 1.3 to 229 cm (0.5 to 90 in.) in virtually any machinable material to suit the application. Types 302, 304, and 316 stainless steel, hastelloy, and monel are stocked for immediate delivery. Orifice flange unions, fittings to allow removal without interrupting service, straightening vanes, and meter runs for highest accuracy are also offered by VSI.

Flow Nozzles - VSI manufactures flow nozzles for critical and subcritical flow in accordance with ASME standards. These are available in carbon steel, chromo moly, and stainless steel in sizes from 2.5 to 76 cm (1 to 30 in.). For guaranteed accuracy, flow-calibrated meter runs are also manufactured.

Venturi Tubes - VSI manufactures a number of venturi tubes including a fabricated type (welded, not cast) ASME, a short form, and a low pressure loss venturi. The fabricated, long-form (ASME) venturi is lighter in weight and more durable than cast or forged venturis. The short-form venturi, while offering standard venturi accuracy (±0.75% uncalibrated), requires less laying length (four times the pipe diameter) and produces only slightly greater unrecovered pressure loss. The low pressure loss venturi or flow tube is a special design that maintains good uncalibrated accuracy (±1%) but offers only about one-fourth the pressure loss of a standard venturi (typically 3% with a beta ratio of 0.75).

All VSI venturi tubes are available in a wide range of standard sizes from 7.6 to 122 cm (3 to 48 in.) and four beta ratios (0.375, 0.490, 0.630, 0.750). Other sizes and ratios can be manufactured for special situations. A partial list of standard materials includes carbon steel, various stainless steels, cast iron, PVC, and fiberglass. Interior coatings of nickel plating, tungsten carbide, or glass lining are available to suit special applications. Insert types are offered as well as flanged and weld-in designs. Both single pressure tap designs as well as multiple taps with an interval annulus are offered.

Parshall Flumes - VSI manufactures Parshall flumes, in all sizes, made of fiberglass, steel, or prestressed concrete. They are available with or without a built-in electronic flow element (liquid height gage); rate indicators, recorders, and totalizers are also available.

Turbine Flowmeters - VSI manufactures insertion-type turbine flowmeters for use with or without a check valve. In-line types with threaded or flanged ends are also available. They are offered for use in pipe sizes from 7.6 to 244 cm (3 to 96 in.).

PRICES:

Prices were not available at time of writing.

COMMENTS:

VSI manufactures a wide line of primary flow measurement devices and will assist customers in assembling complete flow measurement systems. All of these devices were discussed in Section VI and will not be commented upon further here.

MANUFACTURER: WALLACE-MURRAY CORPORATION
CAROLINA FIBERGLASS PLANT
P.O. BOX 580
510 EAST JONES STREET
WILSON, NORTH CAROLINA 27893
TELEPHONE (919) 237-5371

PRODUCT LINE: PARSHALL FLUMES

DESCRIPTION:

Wallace-Murray manufactures a variety of products made of fiberglass reinforced plastics, including a line of standard Parshall flumes. These flumes feature maximum chemical and corrosion resistance, under normal conditions, through their use of polyester resins. Wallace-Murray offers flumes of varying depths and several optional features. Throat widths are available from 7.6 to 121.9 cm (3 to 48 in.); lengths range from 0.3 to approximately 3.35m (3 to 11 ft).

A standard feature of the Wallace-Murray flume is a head gage molded into the side of the flume at its lower end for the measurement of free flow discharges and flows under partially-submerged conditions. A free flow discharge graph is used in conjunction with the gage to determine flows under these conditions. Under submerged conditions, head flow must be measured at both upper and lower locations. By using flow correction curves, a determination of the flow loss due to submerged conditions can be made. Head gages at the second location are optioanl and will be supplied upon customer request.

Optional features of the Wallace-Murray devices include the incorporation, on some models, of a 30.5-cm (12-in.)-diameter floatwell (may be mounted on either side of the flume) or a 5-cm (2 in.) tap for the installation of a remote floatwell or bubbler system. A sanitary white gelcoat interior surface is also available. Installation design features of the flume includes the provision for free standing installation with additional reinforcing ribs or stiffeners optional for maximum stability instead of the standard loops for anchoring when used as liners in concrete.

PRICES:

Prices not available at time of writing.

COMMENTS:

Parshall flumes were discussed thoroughly in Section VI and will not be commented upon further here.

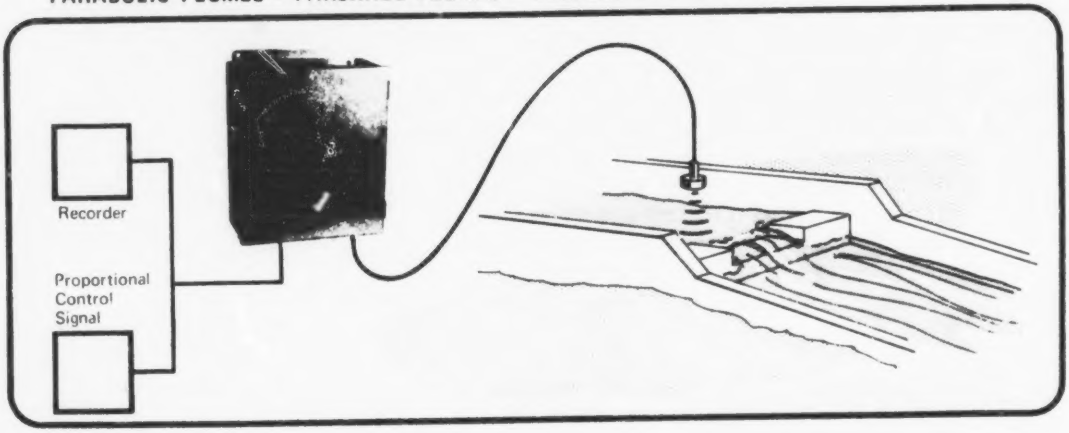
MANUFACTURER: WESMAR INDUSTRIAL SYSTEMS DIVISION
905 DEXTER AVENUE NORTH
SEATTLE, WASHINGTON 98109
TELEPHONE (206) 285-2420

PRODUCT LINE: ULTRASONIC MEASURING DEVICES

DESCRIPTION:

The Industrial Systems Division of WESMAR (Western Marine Electronics, Inc.) manufacturers several secondary liquid measurement devices utilizing the techniques of ultrasonic (sonar in air) ranging. These are the FM 9, a noncontact ultrasonic liquid level "flowmeter" for flumes and weirs, and SLM 9 and SLM 15 ultrasonic devices for the measurement of liquid levels. These devices are all readily adaptable to water and sewage applications.

FM 9 Flow Meter - Actually an echo-sounding instrument, the FM 9 represents a new concept of noncontact weir/flume flow measurement (actually level monitoring) involving no moving parts or mechanical linkage. An all solid-state device, the FM 9 (Figure A) consists basically of an electronics unit (control box), PVC-encapsulated sensor, a meter, and a junction box (JIC enclosure).



FOR:
RECTANGULAR WEIRS • CIPPOLETTI WEIRS • TRAPEZOIDAL WEIRS • "V NOTCH" WEIRS
PARABOLIC FLUMES • PARSHALL FLUMES • LEOPOLD-LAGCO FLUMES

Figure A

This device employs a sensor, which is placed above the liquid level. A repetition rate generator in the electronics unit triggers an oscillator that sends a signal through a driver and power amplifier to the sensor which converts these pulses into high frequency sound waves. The sensor directs these acoustic signals downward to the material. The sensor detects the returning sound wave (echo) and converts it to an electrical signal. Precision timing circuits are used to measure the time delay for the echo to return. Processing of the electrical signals converts the pulse transmit time to an analog voltage or current proportional to the measurement distance. Output is available which represents height or flow. Temperature compensation circuitry neutralizes any temperature variations.

SLM 9/SLM 15 Level Monitor - These are short-range liquid level monitors which are entirely self-contained and are designed to interface with standard industrial meters, recorders, and equipment of all types. Solid state techniques, including the use of integrated circuits, have been employed.

A basic system consists of an electronics board (power supply, transmitter, receiver) and totally encapsulated PVC sensor. The SLM 9 provides noncontact level measurement for distances up to 3m (10 ft) from the sensor. Proportional 0-5 volt and 0-1 mA outputs are standard. Options include: 4 to 20 mA current output; various meters and enclosures; and five independently adjustable set points that may be set at desired level points for pump control, alarm indicators, or annunciators. Operating principles for liquid measurements are similar, from an electronic and acoustic standpoint, to those of the model FM 9 flow meter.

SPECIFICATIONS:

Range (minimum):	FM 9/SLM 9 - 41 cm (16 in.) SLM 15 - 46 cm (18 in.)
Range (maximum):	FM 9 - 3m (10 ft) SLM 9 - 3m (10 ft) (liquids) SLM 15 - 7m (20 ft) (liquids)
Resolution:	within 1%
Repeatability:	within 1%
Linearity:	within 1%
Output Signals:	FM 9/SLM 9 - 0 to 5 VDC 0 to 1 mADC
	SLM 15 - 0 to 5 VDC 0 to 1 mADC (1 to 5, 4 to 20, 10 -50 mADC)
Sensor Beam Pattern:	7° conical included angle

Input Power:	110/220 VAC, 50-60 Hz, 10 watts
Electronics to Sensor Remote Operation:	FM 9/SLM 9 - up to 91.4m (300 ft)* SLM 15 - up to 152.4m (500 ft)*
Dimensions (Enclosure)	30.4x25.4x12.7 cm (12x10x5 in.)
Weight:	
Electronics	0.91 kg (2 lb)
Sensors	0.45 kg (1 lb)

PRICES:

Only general cost guidelines can be provided due to the many variables. Complete systems range from $1,500 to $2,500. Sensors cost from $125 to $150 and control boards are from $500 to $800. Enclosures (junction boxes) are available from $25 to $500, depending upon size and NEMA rating.

COMMENTS:

Ultrasonic liquid height gages were discussed in Section VI and will not be commented on further here.

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* Using Coaxial Cable RG620.

MANUFACTURER: WESTINGHOUSE ELECTRIC CORPORATION
OCEANIC DIVISION
P.O. BOX 1488, MAIL STOP 9R30
ANNAPOLIS, MARYLAND 21404
TELEPHONE (301) 765-5658

PRODUCT LINE: ACOUSTIC FLOWMETER

DESCRIPTION:

More than 10 years of research in the flow measurement field by Westinghouse has gone into the development of this acoustic measuring system. The Model L. E. (leading Edge) Flowmeter is so named because it uses only the leading edge of an acoustic pulse as a basis for determining liquid velocity and volume flow rate. While this flowmetering system was designed to measure water flows, the basic principle applies to most other liquids as well, including raw sewage.

Two ultrasonic transducers are installed in opposite walls of a conduit, with the line between them at an angle (45°, for example) with the conduit axis. The two transducers simultaneously transmit pulses of sound energy through the moving fluid. The pulse moving with the flow travels the distance between transducers in less time than the pulse moving against the flow. The system measures the transit time of the faster pulse and the difference between the transit times of the faster pulse and the slower pulse. Using these two time measurements, it solves two simultaneous equations in two unknowns - the sound velocity and the fluid velocity. Sound velocity can vary with changes in fluid temperature, salinity, and other properties. By measuring sound velocity and correcting for it, the system automatically maintains its accuracy for varying fluid conditions. Volumetric flow through a conduit is computed by integrating the local fluid velocity over the conduit cross section. The system does this by measuring local velocities along several paths, scaling these velocities for path geometry, and summing. A pair of transducers is required for each path. Four transducer pairs (four paths) will achieve better than 1% accuracy with any practical velocity profile. Volumetric flow in an open stream is computed in a like manner, except that water stage is measured and accounted for as it varies.

Figure A shows a basic acoustic configuration arrangement. Two probes are shown in the diagram, each with separate transducers and transmitters; however, in actual practice only one transducer is generally used in each probe, and both probes are energized by a common transmitter. The probes provide an unobstructed flow path without head loss.

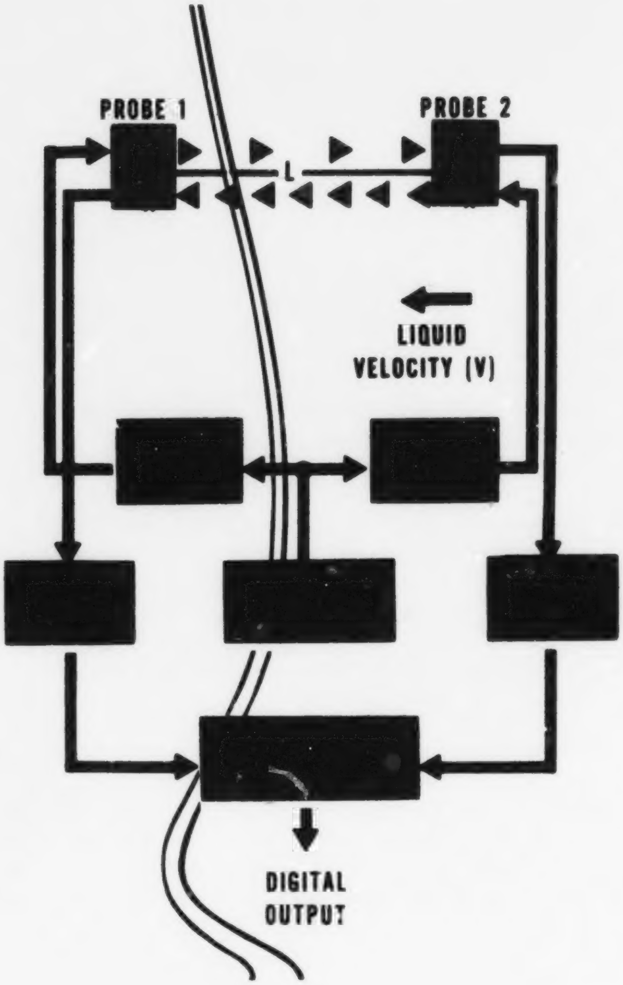
PROBE 1
PROBE 2
L
LIQUID
VELOCITY (V)
DIGITAL
OUTPUT

Figure A

The basic L.E. system consists of the transducers and transducer fittings, cabling, and a console housing the electronic circuitry and readouts. Four pairs of transducers are provided for flow in conduits; in open channel applications, the number of transducer pairs must be determined by the installation geometry.

SPECIFICATIONS:

Accuracies:	to 0.1% (demonstrated) in pipes from 0.3 to 9.14m (1 to 30 ft)
Operating Range:	10,000 to 1 (typical)
Power (Console):	115 VAC, 60 ±2 Hz, 3 amps, <500 watts
Flow Rate:	No upper limit. Flows approaching 16,990,000 ℓ/s (600,000 cfs) have been measured. Liquid velocities to >0.5 percent of full scale.
Dimensions (Console):	198x63.5x63.5 cm (78x25x25 in.)
Weight (Console):	136 kg (300 lb)

PRICE: $40,000 up

COMMENTS:

Section VI discusses the advantages and disadvantages of this type flowmeter. Cost, size, and complexity of this system mitigate against its use for many storm and combined sewer applications.

SECTION VIII

SELECTED PROJECT EXPERIENCE

In order to evaluate both standard, commercially available flow measurement equipment and custom engineered equipment in actual field use, a survey of recent USEPA projects in the storm and combined sewer pollution control area was conducted. Several USEPA projects designed solely to develop improved flow measurement equipment were included in the survey. Final reports were obtained where available, but for some projects only interim reports existed and, in a few instances, telephone conversations had to be relied on. The projects are discussed in general chronological order, starting with earlier efforts and finishing with current, on-going activities.

A survey of recent activities of several other Federal agencies in research and development of improved flow measuring devices and methods is also included herein. The responsibilities of these agencies include measurement of water, so they are familiar with flow measurement needs to fulfill their own objectives. In a few cases, these needs include measurement of stormwater and combined sewage. Contacts with key personnel of the agencies were made by personal interview, by telephone, and by letter.

CHARACTERIZATION AND TREATMENT OF COMBINED SEWER OVERFLOWS

Reference (73) describes a study whose general objectives were: (a) to develop workable systems to manage overflows from the combined sewers of San Francisco, thereby alleviating pollution and protecting beneficial uses of local receiving waters, and (b) to provide the rationale and methodology for controlling pollution from combined sewer overflows in other metropolitan areas of the United States.

Data collection for the project included measurement of dry weather flows of the Selby Street and Laguna Street trunk sewers and measurement of storm overflows from the two sewers. Eight storm overflows were monitored at the Selby Street outfall and two were monitored in the Laguna Street outfall. Monitoring included measurement of rainfall and discharge as well as the quality characteristics of the overflows.

The tracer dilution method was selected for use in measurement of dry weather flows. Pontacyl Brilliant Pink B fluorescent dye was used for the tracer, and quantitative analyses for the tracer were made with a Turner Model 110 Fluorometer. Selection of the tracer was based on the following advantages:

a. Only small quantities of dye are required because precise determination of the dye concentration is possible at 10^{-3} mg/ℓ. Thus cost and quantity requirements are reduced.

b. In most sewage flows the "background" of this particular dye is not significant. The amount of tracer does not have to be materially increased in order to eliminate spurious background effects.

c. The tracer is not significantly affected by the presence of materials normally found in sewage.

Use of the dilution method did not prove satisfactory for measurement of the Selby Street overflow. Uneven distribution of the tracer when injected resulted from exposed sludge banks, and there was insufficient turbulence for adequate mixing of the dye. Because of the resulting lack of reliable data, a Palmer-Bowlus flume with a 1.22m (4 ft) throat and 15 cm (6 in.) invert slab, constructed from 16 gauge galvanized sheet metal was installed. A continuous record of the upstream water level was obtained by mounting a Stevens water level recorder, operated by float, in a stilling well constructed of sandbags.

"Because of adequate mixing below the point of dye injection, the tracer dilution method gave consistent results at Laguna Street and no other method was used for flow determination."

Because of generally unsatisfactory conditions, several methods were used for the measurement of storm flow in the Selby Street outfall structure. These were:

a. Velocity determination with current meters at a point 15m (50 ft) above the outfall structure. Not considered to yield reliable data as the meters were immediately fouled with rags and other debris.

b. Differential head measurements over the broadcrested weirs of the outfall structure. Because of expected interference by tide gates, the theoretical head-discharge relationship for a broad-crested weir of similar shape was used for comparison purposes only.

c. Measurement of surface velocities in the outfall structure by timing the traverse of styrofoam floats across a measured control section. A factor of 0.64 was applied to surface velocities to convert to average velocity, thus accounting for both horizontal and vertical velocity distributions.

d. Measurement of vertical velocity profiles in the outfall structure with an especially designed current meter having low velocity sensitivity. This was to establish discharge values under low head conditions and to check the results of the surface velocity determinations.

Water levels in the outfall structure were continuously measured by means of a "bubbler" gage. A rating curve was developed from the results of the surface velocity determinations and the current meter measurements in the outfall structure. A theoretical curve computed from the broadcrested weir formula was approximately 10% larger than this developed curve.

Flow determinations in the Laguna Street overflow were made by measuring the depth of flow at the outfall sewer and calculating the discharge by means of the Manning equation. Use of the Manning equation was said to be justified because the slope of the outfall sewer is known, and a uniform reach extends about 210m (700 ft) upstream from the point at which depths of flow were determined.

STREAM POLLUTION AND ABATEMENT FROM COMBINED SEWER OVERFLOWS - BUCYRUS, OHIO

Reference (74) contains the results of a detailed engineering investigation and comprehensive technical study to evaluate the pollutional effects from combined sewer overflows on the Sandusky River at Bucyrus, Ohio, and to evaluate the benefits, economics and feasibility of alternate plans for pollution abatement from the combined sewer overflows. A year-long detailed sampling and laboratory analysis program was conducted on the combined sewer overflows in which the overflows were measured and sampled at three locations, comprising 64% of the city's sewered area, and the river flow was measured and sampled above and below Bucyrus.

Dry weather wastewater flow measurements were taken of the discharge from three sewer districts, the influent and effluent of the wastewater treatment plant, and the Sandusky River at upstream and downstream gages. A weir was installed in each of the three trunk sewers, a 90° V-notch weir, a 61 cm (24 in.) rectangular weir, and a 46 cm (18 in.) rectangular weir. For two days of the investigation, flows at the weirs were measured and sampled at 15-minute intervals for 24 hours. The Sandusky River, upstream and downstream, was measured and sampled at one-hour intervals for 24 hours. Also, the wastewater treatment plant influent and effluent were sampled at one-hour intervals and flow measurements taken from the plan records. No problems with equipment for measurement of dry weather flows were indicated.

To measure overflow during rainfall, rectangular weirs were built at each of three overflow points. The weirs were constructed of one-inch plywood, which was bolted onto (steel) angles imbedded in concrete. The weir plates were 2.4, 4.9, and 3.0 meters (8, 16, and 10 ft) long for Numbers 8, 17 and 23 overflows, respectively.

Water level recorders were mounted in instrument shelters 107 cm (42 in.) behind the weirs. The recorders were Stevens Type F Recorder, Model 68, with a 24 cm (9.6 in.) per day time scale and a 1:2 gage scale. All recorders were equipped with automatic starters which would start the clocks at predetermined water levels.

A continuous record of flow in the Sandusky River above and below Bucyrus was obtained for the study period. An existing recording gage operated by the U.S. Geological Survey located at the first bridge below the wastewater treatment plant was utilized for downstream flow measurements. A new gaging station was installed on the river 91m (300 ft) upstream from the first overflow point of the combined sewer system. A rating curve for the gage was plotted using standard gaging techniques. The recorders used at both gaging stations were the Stevens A35, with 1:6 gage scales. The time scales for the gages were 12.2 and 6 cm (4.8 and 2.4 in.) per day, for the upstream and downstream gages, respectively.

No specific problems with flow measurement equipment were reported. However, a tabulation of overflows indicates that no record was obtained at Numbers 8 and 23 overflows during some periods. Reasons for this loss of record were not given. No check on the accuracy of the records was made available.

ENGINEERING INVESTIGATION OF SEWER OVERFLOW PROBLEM - ROANOKE, VIRIGINA

Reference (75) reports on the results of investigations of 25% of Roanoke, Virginia's separate sanitary sewer system, on the amounts of infiltration for various storm intensities and durations, and on the amounts of sewage overflow from the system.

Flows in three sanitary sewer interceptors, and streams draining the corresponding basins, were gaged during storm events to measure infiltration and runoff quantities and to establish their relation to rainfall intensities and durations. After significant variation in dry weather flows was observed, continuous monitoring of flows in the interceptors was maintained. Overflows bypassing the Water Pollution Control Plant were measured during rainfall events.

Sharp-crested weirs were used to measure flows in two of the streams. In the third stream, a stage-discharge curve was developed from the Manning formula using the measured hydraulic characteristics of the stream. In two of the interceptor sewers, and in the Water Pollution Control Plant overflow, a stage-discharge curve based on the Manning formula and the measured hydraulic characteristics of the sewer were used to convert depth measurements to flow estimates. In the third interceptor sewer, dry weather flows were estimated using the Manning formula, but during rainfall events the sewer became surcharged and overflow was measured by means of a weir installed in the side of the manhole wall.

No problems with use of the streamflow measurement devices and methods were noted. However, accuracy of measurements with use of the Manning formula in the natural stream channel photographed must be considered very poor. A photograph of one of the weirs used for streamflow measurement shows a significant accumulation of trash and debris on the weir. Under this condition, accuracy must be considered poor. Hydrographs indicated that two of the interceptor sewers were surcharged during many of the storms, and a record of discharge was not obtained during those periods.

Water levels at the gaging sites were recorded by means of six float-actuated, continuous water-level recorders manufactured by the Instruments Corporation (now a part of Belfort Instrument Company), and one pressure type recorder manufactured by the Bristol Company. After the float-actuated recorders were serviced and supplied with an expanded time scale, they performed satisfactorily for the duration of the program. During dry-weather periods, the bubbler pipe in the Bristol recorder collected debris and required frequent cleaning. Because of this maintenance problem, it was replaced with a float-actuated, continuous water-stage recorder.

COMBINED SEWER OVERFLOW ABATEMENT ALTERNATIVES - WASHINGTON, D.C.

Reference (76) reports on a project whose objectives were to: (a) define the characteristics of urban runoff in the subject area; (b) investigate the feasibility of high-rate filtration for treatment of combined sewer overflow; and (c) develop and evaluate alternative methods of solution.

Investigative activities included field monitoring of combined sewer overflows at two sites, and of separated stormwater discharges at one site. The monitoring program was conducted over a period of about six months, April 1 to September 23, 1969.

Selection of a satisfactory technique for flow measurement presented a problem. Weirs were not used because backwater elevations would have caused surcharging and flooding at the expected high flow rates. Depth of flow measurements with the use of a steady state empirical equation such as the Manning equation for calculating flow was not used because flow conditions were not steady state during periods of storm runoff. The method selected was use of lithium chloride as a tracer in a procedure similar to that of the salt dilution method (continuous injection type). Use of a lithium salt is said to improve the technique because the background of lithium in wastewater is usually low, and because lithium concentrations at fractional parts per million levels can be accurately and conveniently determined by atomic absorption or flame emission spectroscopy. The slope-area method was used as a check.

A number of difficulties experienced in use of the equipment resulted in loss of flow record during several major storms. Greatest trouble was in clogging or damage to the submersible pump used to collect samples of wastewater required for measuring lithium chloride concentration. Flooding of one of the lithium chloride release stations caused damage to the bubbler instruments used to measure water stage, to the lithium chloride release system, and to other equipment.

Flow rate estimates based on depth-of-flow measurements and the Manning formula were compared with results of the tracer method. Only a very general correlation with significant spread resulted. Large differences in flow were attributed to inaccurate measurement of depth of flow and the assumption of steady-state conditions inherent in Manning's formula.

URBAN RUNOFF CHARACTERISTICS

Reference (77) is an interim report on investigations for the refinement of the comprehensive EPA Storm Water Management Model.

"Detailed information on the watershed characteristics and data on runoff quantity and quality have been compiled from a one year study of a combined sewer watershed of approximately 2380 acres in Cincinnati, Ohio. Collection of these data is planned to continue over a three year period."

Flows at three sites in the sewer watershed were monitored. At two of the sites, flow was actually measured in two tributary sewers immediately upstream from their junction. The third site was at the outlet of the watershed; thus, five sets of flow measuring equipment were used.

"The flow measuring apparatus consists of a compressor, a manometer, and a Taylor pressure-type recorder. This recorder operates by measuring the pressure due to the depth and velocity of water flowing into the pipe by bubbling air through a long tube inserted into the water. The gage releases air at a constant pressure and as the depth and the velocity of flow changes, the pressure differential is recorded on a circular chart in inches of water. This pressure differential is actually the specific energy which is equal to the sum of the pressure head (depth of flow y) and the velocity head ($V^2/2g$). To obtain readily the discharge corresponding to the measured specific energy, Manning's equation has been used to express the depth and the velocity of flow as functions of the discharge and the hydraulic radius of the sewer cross sections."

Thus, curves have been calculated relating the measured specific energy and the corresponding discharge at the five measured locations.

Apparently, the value of slope used in the Manning formula was that of the sewer line at each of the five measuring sites. A photograph in the report shows a heavy, metal, top-hanging gate at the outlet of the sewer watershed. The outlet flow monitoring site is described as about 6m (20 ft) upstream from this gate. If this is the case, flow past the site probably would not be uniform, and the Manning formula would not be applicable.

Flows in the two pairs of sewers just upstream from their junction with the two sewers to be monitored would be controlled by the slopes of each of the two monitored sewers rather than the slopes of the four tributary sewers immediately upstream, which were the slopes in the Manning formula to compute flow. In any case, water surface slope is more properly used with the Manning formula than is the sewer slope.

Plotting of storm hydrographs for the measured sites discloses a number of serious inconsistencies in the data.

STORM AND COMBINED SEWER POLLUTION SOURCES AND ABATEMENT - ATLANTA, GEORGIA

Reference (78) reports on a study of six urban drainage basins within the City of Atlanta, Georgia, served by combined and separate sewers, to determine the major pollution sources during storm events. Rainfall frequency analysis and simulation techniques were utilized to obtain design criteria for alternative pollution abatement schemes.

Measurements of flow were made of three major overflows, as well as of the interceptor sewers originating at these points of overflow. Three branches of South River were measured, as was the South River main stream at four points. A bypass at the interceptor entering one of the wastewater treatment plants was measured.

Data were collected from January 1969 until April 1970. Continuous flow monitoring was maintained at the river and its tributary stations, and in the interceptors where dry weather flow characteristics were of interest. Event monitoring only was conducted of overflows and of the bypass to the treatment plant.

Rating curves for all gaging stations were developed by stage-discharge measurements with current meters. Either Price Type AA or Pigmy Type current meters were used. Some discharge measurements were verified by alternate methods or formulas, but results of these verifications are not given.

Stevens Type F water level recorders were used throughout. Gaging stations were reported to be constructed in accordance with established U.S. Geological Survey practice. For flow level recording at interceptors, scow floats were installed at manholes a short distance downstream from regulators.

Although probable accuracy of the records collected was not reported, an indication of their accuracy is available, based on one of the gaging stations in the project which was operated by the U.S. Geological Survey. This station, having a drainage area of 3.86 sq km (1.49 sq mi), had been operated since October 1963, or for more than six years. The greatest flow measured by current meter during the period was 5947 l/s (210 cfs), but the rating curve was extended to 23,220 l/s (820 cfs) by computation of flow through a culvert. Records at the station are stated by the USGS as poor, with no qualification.

STORMWATER PROBLEMS AND CONTROL IN SANITARY SEWERS - OAKLAND AND BERKELEY, CALIF.

Reference (79) describes an engineering investigation conducted on stormwater infiltration into sanitary sewers and associated problems in the East Bay Municipal Utility District, Special District No. 1, with assistance from the cities of Oakland and Berkeley, California. Rainfall and sewer flow data were obtained in selected study sub-areas that characterized the land used patterns predominant in the study area. Results obtained were extrapolated over large areas.

Palmer-Bowlus flumes were installed at three of the ten metering stations established specifically for the study. These flumes were constructed of stainless steel and were designed to fit the respective sizes and shapes of the sewers. They were mounted in the outlet sewer from the manholes so that head measurements could be made at the proper distances upstream from the throats. Wooden channel extensions through the manholes were installed to prevent water spreading out in the manhole as depth in the sewer increased.

At seven of the new metering stations, 90-degree, V-notch weirs were installed. These were constructed of marine plywood and covered for additional water resistance with two coats of polyurethane finish. For ease of installation, a channel closure was provided so that it could be easily slipped down into the flowing sewage and quickly bolted in position after installing and sealing the actual weir plate. Stevens type 2A35 water stage recorders were used at three weir locations where submergence of the weir was anticipated. These recorders were selected for the ability to record two liquid levels simultaneously, upstream and downstream from the weir.

Taylor pressure recorders were installed at the other seven new metering stations. With these recorders, liquid level sensing consists of measuring the back pressure from a continuously purging nitrogen gas bubble system.

In several cases, equipment was installed in manholes near the centers of streets, thus complicating the installation and use of equipment. Otherwise, no problems were noted with the use of the equipment at the newly established stations.

The flow rate at two pumping stations was determined by means of a system-head curve for the station which gives the discharge rate for each pump or combination of pumps. A recording ammeter was attached to the pump electrical leads to indicate the total number of pumps running at any given time. Relief overflow at one of these pumping stations was measured by means of a broad-crested weir and a wet-well liquid level recorder.

A third pumping station was equipped with both a wet-well liquid level recorder and a flow recorder. The primary device for the flow recorder was a venturi flow tube mounted on the discharge manifold of the pumps.

The influent pumping station at the water pollution control plant was equipped with individual flowmeters on each pump discharge which were connected to a combined flow recorder. The primary devices for the flow recorder were the discharge weirs in the grit chambers which reflect the respective pump discharge rates.

A pumping station relief overflow structure was provided with a flow measuring device for measuring the volume of water that overflowed. The flow measuring arrangement consisted of measuring the liquid levels on both sides of a rectangular tide gate and extracting the flows from the manufacturers rating curve. Because of difficulties in installation and operation, no usable flow measurements were obtained during periods of overflow.

DISPATCHING SYSTEM FOR CONTROL OF COMBINED SEWER LOSSES

Reference (80) describes a regulator control system which is said to demonstrate impressive reductions in combined sewer overflow pollution of the Mississippi River in Minneapolis and Saint Paul.

A mathematical model has been prepared that will, using rain gage data for inputs, (a) perform rainfall runoff analysis; (b) divert combined sewer runoff hydrographs at the regulators; and (c) route the diverted hydrographs through the interceptor system. This model will assist in operation of the system to retain combined sewer flows and utilize the maximum flow capacity of the existing interceptor sewer system.

The project includes a computer-based data acquisition and control system that permits remote control of modified combined sewer regulators. Data from rain gages, regulator control devices, trunk sewers and interceptors, and river quality monitors provide real-time operating information.

Water surface elevations in the system were monitored at about 48 points by the installation of bubbler gages employing a pressure-carrying tube installed in the sewer, an air-supply cylinder, a bubbler, a pressure transducer, and a telemetry unit for transmitting data to a central location. This equipment provided information on the frequency and duration of overflows. Because flow rate was not measured, data on the volume of overflows were not thus determined.

Flow in each of the three Minneapolis interceptors at the Minneapolis-St. Paul city line, was metered by dual venturi meters in each interceptor. This equipment, which was in use prior to the subject study, provides information on the effectiveness of the program to use the interceptors for temporary storage of combined sewage. Flow data in the interceptors served to provide a check on the accuracy of rainfall runoff modeling. Probable error of flow measurement by the venturi-meters was not discussed.

PRECONSTRUCTION EVALUATION OF COMBINED SEWAGE DETENTION FACILITIES

Reference (81) presents the result of a lengthy study of combined sewer flows in Somersworth, New Hampshire prior to construction of detention facilities. *"In order to get reasonably accurate and reliable flow measurements it was necessary to replace a section of the outfall with a weir pit large enough to provide a fair amount of stilling behind the weir."* This weir pit was 1.8 x 1.8 x 7.5m (6x6x24.75 ft), and the weir was located 5.6m (18.33 ft) from the inlet.

Three different 0.63 cm (1/4 in.) thick steel plate rectangular weirs with crest lengths of 0.3, 1.2, and 1.7m (1, 4, and 5.6 ft) were used, the 1.2m (4 ft) one being employed for all but three months of the year-long study. The design was such that the different weirs could be changed easily in several minutes. The main difference in the 1.2m (4 ft) weir was that its crest was elevated 1.2m (4 ft) above the floor of the weir pit as opposed to 0.76m (2.5 ft) for the other two. This weir was constructed after initial operation with the 0.3 and 1.7m (1 and 5.6 ft) weirs, and "observation of high flow rates using the 5.6' weir indicated that it was desirable to increase the stilling in the weir pit by raising the crest height."

"Head measurements over the 12" and 5.6' weirs were made using an air operated Fischer and Porter recorder. A float operated transmitter and recorder manufactured by the Penn/Measure-Rite Division of Badger Meter Manufacturing Company was used for head measurements over the 4' weir. Both recorders were set up to use 24 hour, 12" diameter charts. The Fischer and Porter recorder charts had a range of 0 to 20 inches of head, and the Penn/Measure-Rite Recorder charts had a range of 0 to 30 inches.

"Flow into the weir pit was such that some turbulence was created in the weir pit. This caused the flow recorders to print out head measurements in short vertical strokes instead of a smooth line. This condition was corrected as much as possible by the addition of the 4' weir which had a crest 18" higher than the 12" and 5.6' weirs. The added depth of water in the weir pit tended to keep the turbulence at a minimum.

Sludge build-up behind the weirs did not appear to upset the hydraulic characteristics of the weirs. However, before any sampling programs were undertaken, the sludge build-up was totally removed from behind the weirs in order to obtain accurate chemical and biological characteristics of the combined sewage flow. The actual sludge build-up would occur within a couple of days after the installation of a weir. The majority of sludge in this combined sewage flow consisted of grit with a small percentage of organic matter."

Head measurements were "... converted to flows using appropriate formulae for the rectangular weirs used in the weir pit." By this it is assumed that the Kindsvater-Carter equation was used rather than the Francis formula, which would require corrections for both less than standard contraction and velocity of approach much of the time. For example, at the maximum head of 0.6m (2 ft) on the 1.2m (4 ft) weir (any greater head would overflow the 1.8m deep weir pit) the Kindsvater-Carter equation indicates a discharge of around 91 MLD (24 MGD), whereas the uncorrected Francis formula yields approximately 83 MLD (22 MGD), a 10% difference. The maximum discharge for the 1.7m (5.6 ft), as computed assuming the recorder's full 51 cm (20 in.) of head was used, is approximately 98 MLD (26 MGD). Maximum flow rates recorded with the 1.2m (4 ft) weir of from 99 to 148 MLD (26.2 to 39.0 MGD) are reported but not explained. It is possible that the 148 MLD (39.0 MGD) discharge was estimated but not so indicated. The point is that high accuracies should not necessarily be expected with the given installation at the higher flow rates.

URBAN STORM RUNOFF AND COMBINED SEWER OVERFLOW POLLUTION - SACRAMENTO, CALIFORNIA

Reference (82) contains the results of a program to develop a general method for determining the extent of pollution resulting from stormwater runoff and combined sewer overflows occurring in an urban area, and the application of this method to the City of Sacramento, California.

Combined sewage and stormwater in the system were characterized by collecting samples and measuring flows at each of 19 sampling locations during six wet weather periods. The intention was to collect, as nearly as practical, at the commencement of rainfall, three hours thereafter, and approximately 12 to 18 hours after the commencement of sampling.

However, comparison with rainfall records indicates that the first data of each storm period were not collected until the time of maximum rainfall intensity, or later.

The wastewater flows were established at manhole sampling stations by use of the Manning formula. The coefficient of roughness was assumed to be 0.013, a design value used by the City of Sacramento Engineering Department. The value of S used was the measured slope of either the water surface or the invert. Because of difficulties in making the required measurements for determination of slope, flow data at three of the stormwater runoff sites are not considered to be reliable. None of the computed wastewater flows at manhole sampling stations were checked by means of flow measurement equipment.

For design purposes, the peak stormwater runoff flow in each of the individual pipes comprising the Sacramento collection and conveyance system was estimated from rainfall records by use of the rational method. These estimated flows for a full pipe condition can be checked at three locations with computed flows at the manhole sampling stations. They differ with the computed flows by -6, +4, and -32 percent. This agreement is exceptional, particularly as these are the three locations where the computed flows are not considered to be reliable.

STORAGE AND TREATMENT OF COMBINED SEWER OVERFLOWS

Reference (83) describes a project to demonstrate the feasibility and economic effectiveness of a combined wastewater overflow detention basin.

"A paved asphalt detention basin with a storage volume of 8.66 acre-feet was constructed at Chippewa Falls, Wisconsin to receive overflow from a 90-acre combined sewer area including all of the central business district. The system was designed so that the stored combined sewage could be pumped to the wastewater treatment plant when precipitation subsided.

During 1969, due to dry weather, the pond received only sixteen discharges, but completely filled twice and overflow to the river occurred. During 1970, there were 46 discharges and the pond filled once, overflowing to the river. Over the two year period, 37.75 million gallons of combined sewage (93.7 percent of the total discharge volume) were withheld from the river for subsequent treatment."

Overflow from the combined sewer area to the detention basin was measured by a Palmer-Bowlus flume installed in a 198 cm (78 in.) reinforced concrete pipe. The flume was designed as outlined by Ludwig and Ludwig (33). It was fabricated of steel, and installed in the concrete pipe as it was laid. Space between the flume and pipe was grouted.

A Stevens Type A35 water-level recorder with a scow float was installed in the pipe to measure head on the flume. The chart time scale was 73.2 cm (28.8 in.) per day and the gage scale was 1:6. The volume discharged into the pond was computed from the recorded head on the flume and a rating curve for the flume, which was approximated in four linear sections. Discharges indicated by rainfalls on eleven different occasions were missed due to the recorder being out of order. Thus, eleven percent of the runoff events were missed.

Overflow from the pond to the river was measured by a 6.7m (22 ft) long sharp crested weir located in the overflow structure. The weir head was measured by a Stevens Type A35 water-level recorder with a cylindrical float. The chart time scale was 24.4 cm (9.6 in.) per day and the gage scale was 1:6. The recorder was out of order during one of the three overflow events which occurred during the period of project operation.

Flows to the wastewater treatment plant were measured by a meter in the plant which was not described. Apparently, this record is complete.

A THERMAL WAVE FLOWMETER FOR MEASURING COMBINED SEWER FLOWS

Reference (64) is a final report for a project to study the application of thermal techniques to the measurement of flow rates in combined sewers. The volume flow rate was to be computed as the product of average flow velocity in the sewer, and cross-sectional area of flow as determined from a stage measurement.

The use of flush-mounted hot wire or hot film anemometers in a direct reading mode for measurement of average flow velocity was extensively investigated. It was concluded that application of hot film anemometry techniques to commercial application of measuring sewer effluent for extended periods of time was not feasible. Major reasons for this conclusion are: (a) changes in calibration occur due to contamination film build-up; (b) breakdown of protective coatings over long periods of time; (c) change in calibration that occurs due to dissolved gases coming out of solution and depositing on the film element as bubbles; and (d) the physical vulnerability of available probe configurations combined with the difficulty of continuously measuring average velocity.

The thermal wave flow measurement system as developed incorporates five thermal sensors mounted on the inside periphery of the pipe. Measurement of the average flow velocity in the pipe is obtained by averaging the longitudinal propagation velocities of the five thermal waves generated at the five symmetric peripheral positions. Tests of a prototype unit indicated that this configuration does not provide signals which have adequate precision to measure fluid flow with the desired accuracy. The dissipation of heat was determined to be quite large, as was the ratio of the average stream velocity to the apparent boundary layer velocity.

The stage measuring system utilizes an electronic liquid level gage which consists of two solid rods formed to fit the inside curvature of the sewer pipe. One rod is driven by an electrical signal, and the other rod acts as a variable tap whose output varies as a function of water level. The instrument is capable of accuracies better than 1 percent of full scale. This is a commercially available system manufactured by Marsh and McBirney, Inc.

WASTEWATER FLOW MEASUREMENT IN SEWERS USING ULTRASOUND

Reference (84) describes the use of newly developed ultrasonic velocity measurement equipment in conjunction with ultrasonic level measurement equipment for the measurement of sewage flow.

"Each of two existing (combined) sewers in the Milwaukee (Wisconsin) Sewerage System, one 12-1/2 ft and the other 5 ft in diameter, were thus equipped initially. Subsequent discovery of an excessive amount of entrained air at the 12-1/2 ft diameter sewer site necessitated the transferral of that equipment to a more favorable location upstream in a 12-foot diameter sewer. Performance of the ultrasonic meters was compared with other metering devices at each of the locations. Relationships between average volume flow, water level, and average velocity along selected horizontal chords of the sewer cross sections were determined. A continuous record of flow was displayed and recorded. The unit installed in the 5-foot diameter sewer has operated for a period of 18 months without failure and has required only routine maintenance. Similarly the relocated unit installed at the 12-foot diameter sewer site has operated without failure since its installation. No deterioration of the ultrasonic transducer probes has been detected to date indicating their suitability for use in the sewer environment. The electronics of the ultrasonic velocity metering unit were modified to include peak protection, automatic gain control, and automatic trigger control to minimize the effects of variations in the solids loading."

Further observations concerning use of the ultrasonic equipment are as follows:

a. Similar equipment has been used in Japan to successfully measure full pipe flow of return sludge with high solids loadings. For practical line diameters, say from 0.2 to 5m (0.5 to 16 ft), no operational limitations due to suspended solids would be expected.

b. Entrained air bubbles were found to cause operational problems because of dissipation of the ultrasonic pulse due to scattering by the bubbles. Therefore, it is recommended that measurement sites be selected which are reasonably free of severe upstream agitation which would cause air entrainment.

c. Difficulties with level gage performance resulted from standing ripples in the sewage surface which interfered with echo returns. This was alleviated by moving the level sensor a few feet to a point where the sewage surface was more still.

d. Comparative figures of flow as measured by the ultrasonic equipment with those measured by other metering devices are not given for the demonstration sites described.

e. Total system cost for each site was about $15,000. Future simplifications of the ultrasonic circuitry made possible through more extensive use of integrated circuits have the promise of reducing this system cost by a factor of two or three.

BIOLOGICAL TREATMENT OF COMBINED SEWER OVERFLOW AT KENOSHA, WISCONSIN

Reference (85) describes the design, construction, operation and two year evaluation of a biological process used for the treatment of potential combined sewer overflow. A 76 MLD (20 MGD) modified contact stabilization process plant was constructed on the grounds of the city's existing 87 MLD (23 MGD) conventional activated sludge plant at a total cost of 1.1 million dollars.

"During 1970 while design and construction of the demonstration system facilities was occurring, a program to determine the quality of the combined sewer overflows in Kenosha was carried out. This included measurement of rainfall, combined sewer overflow quantity and quality, and influent quality to the WPCP (water pollution control plant) during rainfalls."

Flow measurement equipment was installed in the outfall lines of three overflows, known as the 57th Street, 59th Street, and 67th Street overflows. Depth recorders installed were operated on a differential pressure basis.

"Inert nitrogen gas was introduced into tubing which ran between the recorder and the bottom of the outfall sewer. As the flow (head) in the sewer increased, the nitrogen escaping from the end of the tubing in the sewer was decreased, proportional to the depth of flow, causing the pressure within the tube to increase. This increase in pressure was converted to depth readings and recorded on a circular chart. The chart was divided into 24 equal sections and driven by an 8 day clock."

Depth-discharge relationships were developed for the three overflow lines by means of dye tests. However, no details of the test procedures were given.

As a result of an unsuccessful attempt to correlate rainfall volumes with overflow volumes, it was disclosed that the overflow measuring devices were of questionable accuracy. In some cases, the volume of overflow measured exceeded the volume of rainfall over the combined sewer area. Apparently, the depth-discharge relationships were not accurate and so the overflow data were not used.

Measuring sites at the 57th Street and 59th Street overflows were abandoned in 1972. The depth recorder at the 67th Street site was moved upstream above the weir diverting flow to the interceptor sewer. The end of the bubble tube was placed just upstream from the overflow mechanism, and a formula for broad-crested weirs was used to convert level over the weir into flow rates and volumes. Flows computed in this manner were used to estimate the total volume of overflow to the demonstration treatment plant.

FLOW AUGMENTING EFFECTS OF ADDITIVES ON OPEN CHANNEL FLOWS

Reference (86) describes some laboratory experiments conducted to study the effects of polymer additives on open channel flows. Two sheet steel channels 18m (60 ft) long and painted initially with epoxy paint (n=0.009) and later with a sand and paint mixture (n=0.013) were used in the tests. One channel was rectangular with a bottom width of 15 cm (6 in.) and a side length of 15.2 cm (6 in.) while the other was trapezoidal with a bottom width of 12.7 cm (5 in.), a 60° interior angle, and a side length of 15.2 cm (6 in.). Slopes could be adjusted to 0, 1, 2, 3, and 4%.

A series of tests was conducted to determine the effects of a polymer additive on four types of flow measurement devices. A Parshall flume, 90° V-notch weir, and suppressed rectangular weir were adapted to the smooth-wall rectangular channel and tested at a 1% slope, while a Leopold-Lagco flume and a 90° V-notch weir were tested in the smooth-wall trapezoidal channel at a 2% slope. No sizes are given for any of the flow measurement devices, nor can they be estimated from a photograph in the report except to note that the crest height of the rectangular weir is low (perhaps 20% or less of the channel depth) as is that of the V-notch weir for use in the trapezoidal channel. Conversely, the V-notch in the weir used in the rectangular channel appears to "run out" at the top of the channel.

The general procedure followed was to calibrate each device in place using tap water, and then to inject the polymer to yield a predetermined concentration and develop a new calibration curve. Head was measured using a pointer gage "usually at the inlet to the device". A stop watch, 19ℓ (5 gal) bucket, and scale were used to determine flow rates under 570 ℓ/m (150 gpm) (where most of the data were taken), while an orifice meter was used for higher flow rates.

Calibration of all devices was affected by the addition of polymers. The Parshall flume was least affected, while the V-notch weir suffered a greater calibration curve shift (e.g., discharge could be understated by over 50% of all but the lower flows). The Leopold-Lagco flume and the rectangular weir ceased to be effected as flow measurement devices above a transition flow rate. The data are inconclusive, but indicate that polymer additives can affect primary flow measuring devices and point out the need for careful research in this area.

SURGE FACILITY FOR WET AND DRY WEATHER FLOW CONTROL

Reference (87) represents the culmination of a 3-year demonstration project which encompassed the design, construction, operation, testing and evaluation of a surge facility designed to provide flow equalization and some degree of treatment to all storm flows and to provide rate control of all wet weather and dry weather wastewater flows to interceptor sewers.

The principal elements of the facility are a sedimentation-equalization basin, a clarifier, a storage pond, a chlorine contact basin, and a sludge digester. Flow and hydraulic measurements include: (a) influent to the sedimentation-equalization basin; (b) underflow from the sedimentation-equalization basin to the clarifier and the storage pond; (c) overflow from the sedimentation-equalization basin directly to the storage pond; (d) water surface elevation of the sedimentation-equalization basin; and (e) effluent to the chlorine contact basin and the receiving stream.

The influent metering structure is a Parshall flume with a 0.30m (1 ft) throat width having a maximum capacity of approximately 30 MLD (8 MGD). The influent flow transmitter to the control building can be used to control a flow proportional sampler of the influent.

Underflow from the sedimentation-equalization basin is measured with a 15.2 cm (6 in.) magnetic flowmeter. The underflow can be set at any desired rate up to 8.7 MLD (2.3 MGD).

Overflows from the basin are measured by four sharp-crested rectangular weirs, totaling 2.54m (100 in.). Head on the weirs, and the water surface fluctuations in the sedimentation-equalization basin, are monitored with a Stevens Type F water-stage recorder. Time gears were selected to give an 8-day chart, and stage gears were selected to give an indication of 0.06m/cm (0.5 ft/in.) of chart or 0.012m/cm (0.1 ft/in.) of chart, depending on the depth variation expected during any particular testing period.

Effluent from the facility is measured with a combination of a 15.2 cm (6 in.) Parshall flume and a 137 cm (54 in.) sharp-crested rectangular weir. The two flow measuring devices are set to give a combined capacity of 22.7 MLD (6 MGD). The effluent flow transmitter can be used to control a flow proportional sampler of the effluent.

No discussion of problems with flow measurement equipment is given in the report. Flow data presented in the report appear to be complete and accurate. "*With the influent and underflow metered and the water surface monitored continuously, it was relatively easy to produce a uniform underflow rate during normal dry weather flow periods while maintaining a desired variation in water surface and preventing overflow to the storage pond.*"

A PORTABLE DEVICE FOR MEASURING WASTEWATER FLOW IN SEWERS

Reference (88) is a final report of a program to develop a portable device capable of measuring wastewater flow in sewers. The work consisted of: an investigation of the theoretical approach to be used; laboratory investigations and experiments to develop design criteria; design and fabrication of two prototype units; and field testing and evaluation of these units.

Methods investigated for determination of velocity in the sewer, prior to selection of the heat pulse method for development, are as follows:

a. Capacitance - Air Bubble Method

This method depends upon the electrical capacitance of the wastewater flow cross-section and the effect on this capacitance of the displacement of air bubble tracers as they rise and are swept downstream past a capacitor plate. This approach failed due to "background noise" and, at low velocities, due to too rapid rise of bubbles in the flowing water.

b. Inductive Method

"Utilizes a drive coil external to the pipe to create an audio frequency magnetic field. The magnetic field, in turn, induces an eddy current in any nearby conductor, such as the water in the pipe. This eddy current can be detected by sensitive pickup coils located near the pipe invert. If the water is moving, the signal detected will be out of phase with the stronger signal resulting from direct coupling of the drive and pickup coils, the amount of this phase shift being correlated with effective velocity."

Failure of this method was attributed largely to the extreme smallness of the signal to be detected.

c. Electromagnetic Flowmeter

This included the rather commonly used electromagnetic flowmeter approach for measurement in a full pipe. However, it was decided that bulkiness of the equipment precluded its use for a portable, easily installed instrument.

d. Electric Current Method

A voltage was applied across a dynamic test section, between two electrodes in direct contact with the water. A

> change in d-c voltage was observed as velocity changed. An increase in current was observed as velocity decreased, with the filled cross-section remaining the same. Problems encountered were random changes due to d-c signal "drift", and plating by the direct current on the exposed electrodes.

The method finally selected for more detailed investigation involved the timing of a heat pulse as it traveled down the pipe. Thermocouples were used to sense the travel of heat induced by the injection of steam into the flowing water. Measurement of the cross-sectional area of flow was done by the use of capacitor plates to sense the change in water level in the sewer pipe.

"Two prototype gages were fabricated. The overall accuracy of the final prototype was, at best, ±15 percent."

JOINT CONSTRUCTION SEDIMENT CONTROL PROJECT

Reference (89) describes a demonstration project which consists of: (a) the implementation, demonstration, and evaluation of erosion control practices; (b) the construction, operation, and demonstration of the use of a stormwater retention pond for the control of stormwater pollution; and (c) the construction, operation, and maintenance of methods for handling, drying, conditioning, and disposing of sediment. As part of the project, a gaging and sampling program was conducted to determine the effects of urbanization on storm runoff and water quality of natural areas.

Four automatic flow gaging and water sampling stations were installed on small streams of the study area. Two of the stations were installed adjacent to each other on streams just upstream from their junction. One of these streams drains an experimental watershed and the other drains an adjacent reference watershed. Two other gaging and sampling stations were established immediately upstream and immediately downstream from a 1.6 Hectare (4 acre) pond.

At three of the gaging sites, precalibrated, broad-crested, V-notch weirs developed and tested by the U.S. Department of Agriculture were installed. At two sites, the concrete weir caps have 2:1 side slopes; at the third site, side slopes of the weir cap are at 3:1. At the gaging site downstream from the four-acre pond, a sharp-crested, compound, 90°, V-notch and rectangular weir was installed.

A Stevens Duplex Water-Level Recorder Type 2A35 was used to simultaneously record water levels at the two adjacent stream sites. A Stevens Type A35 water level recorder was used upstream from the pond, and a Belfort liquid level recorder was used at the downstream site.

A Gurley pygmy current meter was available to perform additional stream gaging, but was used primarily to check the calibration of the permanently installed weirs.

The weirs and level recording devices used are said to "have proven to be accurate, reliable, and easy to maintain". However, it was found necessary to clean out sediment above the three U.S.D.A. weirs "--*after each storm and sometimes under base flow conditions to maintain the calibration and accuracy of the weirs*". No cleanout was required at the compound weir downstream from the pond. Because of the reported accumulation of sediment found after each storm, accuracy of runoff records at the three sites during periods of storm runoff may be questioned. An unknown pattern of alternate sediment accumulation and flushing during the storm runoff period could occur. Calibration may have been incorrect during the falling limb of the hydrograph, when sediment was accumulating.

COMBINED SEWER OVERFLOW ABATEMENT PLAN, DES MOINES, IOWA

Reference (90) is a report on a project designed to provide engineering information regarding the volume, character, and impact of combined sewer overflows and urban stormwater discharges from a typical midwestern metropolitan area. The project includes an engineering evaluation of solutions to the problem, including combined sewer separation and investigation of facilities for the treatment of both combined sewer overflows and stormwater discharges.

Several different types of equipment and methods were used to measure flows and to provide secondary stage measurements. Weirs of the 90° V-Notch type and rectangular weirs, both suppressed and contracted, were used. At sites with larger volumes of flow, a stage-discharge relationship was determined using current meters. Natural controls of a permanent nature were found at these sites. The Manning formula, with water-surface slope and an "n" value of 0.018, was used to determine discharge in one conduit. The main outfall of the wastewater treatment plant was measured with a raw sewage flow totalizer of an undisclosed type. Stick gages painted with water soluble paint were used to detect overflow occurrences. Both Stevens Type F Recorder, Model 68, and project designed and fabricated compressed-air bubbler recorders were used to record water levels.

Dry-weather sanitary sewer flows were measured in eight sewers and in the main outfall of the wastewater treatment plant. Weirs were used in all sewers and float recorders were used in seven of them. A bubbler recorder was used in the eighth. No problems in measuring dry-weather flows with this equipment were reported, although no check on accuracy is available.

Because of the extended period of high river stage, flow measurements during wet weather were generally not obtained in the sewers or overflow points. During this period, most of the flow measuring sites were either submerged or at least intermittently affected by high water. Overflows at one point were estimated by use of the Manning formula, and at another point by use of a current meter.

Stormwater runoff was measured at four gaging sites on storm sewers. At three sites, flow was measured by means of weirs and bubbler recorders. During periods of high river stage, one of these sites was submerged or affected by backwater, when no record was obtained. Runoff at the fourth site was determined from a stage-discharge relationship established by current meter measurements. A concrete sewer line crossing the channel provided a permanent type control. The rating curve was extended an undisclosed amount above the highest current meter measurement.

COMPUTER MANAGEMENT OF A COMBINED SEWER SYSTEM

Reference (91) describes a computer-controlled "total systems management" complex, which affects much of the combined sewer system of Seattle, Washington. Computer-augmented treatment and disposal (CATAD) takes advantage of storage in the sewers to limit overflows, and selects overflow points based on water quality data.

Development of the control system included the installation of 36 remote sensor stations and the construction of 15 gate-driven regulator stations. Work continues on a fully automatic optimizing model to program decisions so the system can maintain an 80% overflow reduction.

"Water levels at many locations are probably the most important single category of information required to calculate flows and trigger certain types of alarms. By incorporating Manning's equations, various orifice and weir formulae and pump efficiency curves, it is possible to calculate flow at almost any location in the system. The computer checks water elevations with reference to overflow weirs to generate pre-alarms before overflows take place and/or actual alarms after the overflow has begun. Monitoring, control and modeling of the entire system depends upon flow information from many locations, some of which cannot be obtained from water level measurements alone. In the CATAD system, these additional on-line flow measuring techniques are employed:

1. *Flow measuring weirs are installed at various locations.*
2. *A calibrated propeller type flowmeter is monitored at the West Point treatment plant site.*
3. *Force main pressure calibration methods are used at pump stations where there is sufficient friction head loss to calibrate the force main at various flow ranges."*

In addition, more than 100 Palmer-Bowlus flumes are installed in manhole locations. A computer program has been applied for rating these measuring flumes, using data including sewer diameter, shelf height, flume side slopes, and elevation of vertical side slopes.

Level sensors used in the system are generally pneumatic bubblers with back pressure read by a differential pressure transmitter. The accuracy of measurements was checked by direct level measurements to bring instrument calibration of the various stations into agreement with the system datum. It was determined that the overall accuracy probably approaches about 2% of the full scale measurement.

Project experience demonstrated that manufacturer's pump unit performance curves may be used to calculate reliable flows provided that critical analog sensors, particularly pump speed sensors, are reliable.

Because flows calculated using performance curves had been considered dubious, force main pressure sensors were installed at many pump stations to provide alternative means of calculating station discharge. As a result of checking the pressure gages using the salt velocity method, it was found that flows thus calculated are not entirely reliable due to rapid fluctuation of analog pressure values.

Deficiencies in the flow calculation procedures for regulator stations were revealed. No allowance had been made for the effect of interceptor backwater affecting the tailwater at a regulator gate and no transition had been provided between fully-submerged and free discharge conditions. A backwater allowance was added, and a method of calculating the degree of gate submergence was developed.

CHARACTERIZATION AND TREATMENT OF URBAN LAND RUNOFF

Reference (92) describes a project to characterize the runoff from a 4.3 sq km (1.67 sq mi) urban watershed in Durham, North Carolina with respect to annual pollutant yield. The U.S. Geological Survey operates a continuous stage recorder and two digital punch tape precipitation recorders within the basin. Stream-flow control is provided by a shallow V-notch weir located on Third Fork Creek some 21m (70 ft) downstream from a bridge culvert and 11.3 km (7 mi) upstream from the mouth of Third Fork Creek. Water quality samples were taken from the center of the stream approximately 1.5m (5 ft) below the weir. Thus, rainfall, runoff, and water quality data were gathered for the basin and analyzed. The USEPA Storm Water Management Model (SWMM) was also evaluated with respect to actual conditions as measured in the field and "was judged to predict peak hydrograph flows and total hydrograph volumes with reasonable accuracy; however it was not judged effective for predicting pollutant concentrations".

In order to assess the impact of varying types of land use within the basin on urban runoff quality, 5 storms were manually sampled at subbasin discharge locations. A control section, usually a pipe or box culvert, was utilized with Manning's equation to arrive at stage-discharge relationships for each basin sampled. The stage was manually read when a sample was taken. No accuracy estimates are available.

OTHER USEPA PROJECTS

Among USEPA projects for which final reports are not available is a project (EPA S-802400) to demonstrate disinfection and flash treatment of combined sewer overflows at Syracuse, New York. Disinfection is applied for one minute after solids removal by high rate screening. Flow of combined sewage is measured from three pumping stations to installations of fine mesh and micro screens. Also, flow in solids return lines from the screens is measured and used to control backwash of the screens. Flow from the three pumping stations is measured by Brooks electromagnetic flowmeters. Solids return from the screens is measured with a weir and a Badger Meter, Inc. float level indicator. Problems were experienced in printed circuits of the signal converters used with the Brooks electromagnetic flowmeters. Initially, other problems necessitated that adjustments be made by Brooks' representatives.

A USEPA grant project (EPA Y-005141) with the Monroe County Pure Waters Authority is to develop a master plan for treatment, conveyance, or holding alternatives to effectively handle the combined sewer overflows from the Rochester, New York, sewer system. Flow quantity and quality data collected for the project are to be used in calibrating the USEPA Stormwater Management Model. The master plan is to be so developed to provide guidelines for use in preparing such plans for other cities. Measurements of thirteen combined sewer overflows, and at four locations in interceptor sewers, are being made. At five of these locations, Badger Meter, Inc. ultrasonic flowmeters are used in conjunction with Badger ultrasonic water surface level indicators. At eleven locations, Badger ultrasonic level indicators only are used to record head over weirs or to provide data for use with the Manning formula. A Fischer-Porter bubbler gage above a combination weir-orifice is used for flow measurement at one site. All data are transmitted to a central computer. Redesign of the ultrasonic head probes was found necessary due to echoing in the sewers, but they are now reported to be operating satisfactorily. Problems of interfacing with the computer were experienced, but very good operation has been obtained after six to eight months' experience.

A project (EPA No. 11024 FIU) was for the design, fabrication, and testing of a prototype 30.5 cm (12 in.) vibratory sewer flowmeter. The flowmeter to be developed was to operate on the principle that the reaction of flowing material to a mechanical vibration applied to the stream boundary in a direction transverse to the direction of flow is a direct measure of mass flow rate. The essential elements are an actuator to impart a vibratory force or motion to the flowing material and a sensor to measure the reaction. This type of device has been used successfully for measuring very small flows, but the mechanical problems with equipment for use in a sewer were not successfully solved with the time and funds available.

A project (Contract No. EPA 68-03-0341) with Cushing Engineering is for the "Development of an Electromagnetic Flowmeter for Combined Sewers", which may result in a device capable of measuring flow under open-channel conditions as well as in a full, pressurized pipe is in progress. The open channel electromagnetic flowmeter will have a primary unit or transducer (i.e., the portion through which the fluid flows) that is not considered to be appreciably more complicated than the conventional instrument; however, it does require more sophistication in its secondary unit (i.e., in its signal conditioning unit). The primary unit is very similar to standard electromagnetic flowmeters except that in this case a manifold of detection electrodes (as opposed to a single pair) are employed so that measurement can be made throughout the varying depth of the liquid. The outputs of the detection electrodes are fed into an adder network which totals the voltage sensed in accordance with height of flow.

The EPA has contracted (Contract No. 68-03-2121) with Grumman Ecosystems Corporation for the development of a new, non-intrusive, low cost, passive measurement system capable of monitoring flow in storm, combined, and sanitary sewers. The system's concept involves a proprietary technique of utilizing the sound emission resulting from the interaction of fluid flow with a discontinuity of a solid surface. In the application to sewer flow, a discontinuity is any inherent change in the sewer cross-section, slope, or direction that can significantly affect the flow area or direction. Laboratory investigations directed to optimize system design details for sewer installations, and analyses which will relate theory and test data to measurement system design objectives and applications are currently underway. By proper signal processing, the acoustic emission flowmeter can be made to differentiate between sound that is indicative of and generated by the quantity of flow and noise caused by noncorrelatable secondary flow processes and general background noise. Several factors may affect sound production and transmission in wastes such as a suspension of bubbles, temperature gradients and stratification, etc. These areas must be investigated and either avoided or compensated for by selection of sound pickup locations.

PROJECTS BY OTHER FEDERAL AGENCIES

Federal agencies which have been active in development of improved flow measurmenet equipment and methods, with a brief description of their work, are given below. Other Federal agencies have carried on similar useful projects in past years, but have been omitted where information on possible recent work was not available. The information presented here was obtained either by telephone or personal interview.

Agricultural Research Service

Work on improved designs of trapezoidal-type measuring flumes to overcome sediment problems is being conducted in Phoenix, Arizona.

Bureau of Reclamation

Radioisotope Flow Measurement - Equipment and methods for measuring flows in canals, pipelines, and turbines with radioisotope tracers have been developed by the Bureau during the past ten years. Public resistance to injection of radioisotopes into water supplies has minimized their use.

Ultrasonic Flowmeter - Ultrasonic flowmeter equipment furnished by the Badger Meter Company was tested in a 61 cm (24 in.) diameter pipeline and in a 76 cm (30 in.) wide channel. A measurement accuracy of ±2% was obtained in the pipeline. A significant conclusion was that the flowmeter transducers should be installed in direct contact with the water rather than on the outside of the pipe.

Rotameter-type Flowmeter - Combined rotameter-type flowmeter and flow controllers of 25.4, 30.5, and 35.6 cm (10, 12, and 14 in.) sizes were studied in the laboratory. These devices totalize flow, indicate flow rate, control flow to preset rates, and provide shutoff. Further field operation and experience is necessary to fully evaluate the devices.

The Bureau of Reclamation conducts a continuing research program in the fields of water system automation and flow control. Studies in the use of electromagnetic and ultrasonic methods of flow control are in progress.

Corps of Engineers

Recently, Westinghouse ultrasonic flow measurement equipment has been installed on the Columbia River to provide improved information on powerplant operation. This work was performed by the personnel of the Portland District in cooperation with the U.S. Geological Survey.

Satellite transmission of data is being investigated in the New England Division. Telemark data transmission systems are being discontinued and are being replaced by radio transmission. It is expected that data transmission in the future will be tied to the National Oceanic and Atmospheric Administration System of Automation of Field Operation and Services.

Geological Survey

The Water Resources Division of the Geological Survey maintains a continuing program to improve water measurement devices and procedures.

Recently, a flow measurement device for measurement of storm runoff in sewers has been developed, and a number of them are being installed in several sewered catchment basins. The device functions within the sewer under both open-channel and pressure flow conditions, and is said to cause only an insignificant amount of head loss. Under open-channel conditions, the meter functions as a venturi flume. For pressure flows, the device operates like a modified venturi meter. This flowmeter is very similar to that developed by Dr. Harry G. Wenzel of the University of Illinois. A significant difference is that the upper position of the pipe is unconstricted, reducing discontinuity between the open-channel flow rating and the pressure flow rating.

PROJECTS OUTSIDE THE UNITED STATES

The reader is cautioned not to assume that all the flow measurement research today is being conducted in the United States. Most industrialized countries are active in this area, and new or improved flow measuring devices and techniques are being reported by foreign investigators. Coverage of all foreign research simply was outside the scope of the present effort, but would be a fit subject for a future study.

However, mention will be made of one Canadian development recently reported by Marsalek (93) because of its promise for application at sites troubled by surcharging. It is essentially a flume-dilution combination for sewer flow measurement. The equipment involved is all portable and suitable for manhole operation. At the primary wastewater characterization site a Palmer-Bowlus type flume, a water level recorder (a capacitance-type probe was used in this case), and an automatic discrete sampler were installed. At a manhole sufficiently upstream to assure that complete mixing would occur a tracer supply and metering feed pump were installed.

Under ordinary (open channel) flow conditions only the equipment at the primary site is in operation. When the water level, as measured by the capacitance probe, reached a pre-determined value indicating that submersion effects would be seriously degrading discharge values as measured by the flume, an alarm relay activates the tracer feeding pump at the upstream site. The chemical dilution technique is applied for the "high flow" periods by analyzing the samples collected by the automatic sampler to determine tracer concentrations.

SECTION IX

FUTURE AREAS OF RESEARCH AND DEVELOPMENT

Although the general state of the art of flow measurement has come a long way since the days of Sextus Julius Frontinus (e.g., we can accurately measure cryogenic flows, liquid sodium flows, mixed gas and vapor flows, etc.), the most common flow measurement devices and techniques used in sanitary engineering are but modest improvements upon nineteenth century (or earlier) developments. This is not surprising in view of the National priorities that have been given to space and nuclear energy programs, and the concomitant application of resources to the development of technologies directed toward the solution of problems in these areas. As was pointed out earlier in this report, we are now becoming more and more aware of the importance of accurate sewer flow measurement and, in recent times, have begun to devote increasing attention to it. Storm and combined sewer flows, as noted, are among the most difficult to measure well, and much remains to be done before we can claim that the state of the art, as being practiced, is equal to the task.

As a result of the activities conducted during the course of this study, including the review of older research and development projects as well as current and on-going ones, it appears that there are several promising research areas that could produce improvements within a short-term time frame. They have been divided into three categories: general research, which is more basic or fundamental and applicable to a number of different classes of flowmeters; applications research, which deals with the engineering required to adopt already-developed building blocks into flow measurement systems suitable for the storm and combined sewer application; and demonstration research, which is the actual field use and evaluation of existing equipment that either has not been tried before or about which there is presently insufficient information.

Several promising activities within each area will be discussed. No attempt to be exhaustive or all-inclusive has been made. Rather, the activities suggested have been selected because of a critical need, the promise of a high probability of positive results, and/or the immediacy with which results could be obtained. The selections are necessarily somewhat subjective, and doubtless some readers will be concerned that one of their "pet" areas has not been included. The writers can only hope that any such criticism will be tempered by the realization that a complete coverage of all possible contributory research could more than double the size of this already somewhat lengthy report.

Two general recommendations will be treated outside the just mentioned categories because they tend to overlap and are a bit more policy/priority than specific task oriented. First, there is a need for a facility where controlled flows of wastewater can be maintained so that various alternative devices and techniques can be tested in a side-by-side fashion. It is imperative that this facility be capable of operation with actual sewage as well as water in view of possible interference effects to some flow measurement equipment that might be caused by the former. A facility was developed as a part of a USEPA funded study and evaluation of a periodic flushing system for combined sewer cleansing by FMC Corporation. It has variable slope test sewers of 30.5 and 45.7 cm (12 and 18 in.) diameters and can utilize actual sewage. It is recommended that this facility be evaluated for the purpose of side-by-side flow measurement device testing and so utilized if indicated.

The second general recommendation arises from the very nature of the storm and combined sewer application itself. It is strongly recommended that priority be given to the development of portable flow measurement devices that could be used for overall survey work, for gathering field data for use in the development of computer stormwater management models, for conducting infiltration/inflow studies, and the like. The importance of a portable flowmeter for each of the cited uses is well known and will not be belabored here. The problem is that the need is still largely un-met. Of the following research recommendations, it is recommended that those activities that will be contributory to the development of portable devices be undertaken first.

GENERAL RESEARCH

Much remains to be learned about the physics of complex flows such as stormwater or combined sewage. They are multi-phase mixtures containing solids, liquids, and gases and are unstable, with constituents going into and out of solution as the flow progresses. When combined with the problems introduced by nonuniform, unsteady turbulent flow, the research possibilities are mind-boggling. Only three, which the writers feel are both of immediate concern and reasonable tractibility, will be discussed.

Effects of Entrained Air and Solids

Entrained air and solids in the flow can have an effect on several different types of flow-measuring equipment. One of the most recent and promising methods of flow measurement utilizes ultrasonic equipment, which is known to be adversely affected by these elements. Experience to date has shown that the presence of heavily concentrated air bubbles in the flow interferes with operation of ultrasonic flowmetering equipment. This is true even when the bubbles are so small that they are hardly visible. The only solution thus far proposed is to install the flowmeter where such bubbles do not form; that is, to avoid locations below drops, chutes, and hydraulic machinery which cause air entrainment in the flow. A method for overcoming this restriction of meter applicability is needed, and should be investigated further.

A similar interference by solids suspended in the flow has been noted. Although methods for overcoming the effects of larger, more widely spaced suspended solids have been developed, fine silts remain a problem. Further study to better understand and overcome such effects on ultrasonic velocity measuring devices is recommended.

Polymer Effects

The introduction of selected polymers to pipe flows has been demonstrated to significantly increase the pipe carrying capacity. Flow increases of as much as 240% at a constant head have been achieved. Field tests reported by The Western Company (94) on a 61 cm (24 in.) line demonstrated that surcharges of greater than 1.8m (6 ft) could be eliminated by polymer additives. Similarly, the capacity of open channels has been increased through use of friction-reducing additives, although to a lesser extent, as noted by Derick and Logie (86).

The addition of polymers to the flow can have a significant effect on the calibration of certain types of flow measuring equipment, as also reported by Derick and Logie (86). Although they only tested flumes and weirs, effects could be even more pronounced in those devices that presuppose velocity distributions in the flow. Ultrasonic flowmeters are a particular case in point. For example, little is known about the effect of changing the viscosity of the water on the character of the ultrasonic pulse through the water, or about the reduction of turbulence causing a change in velocity distribution in the cross-section. Because of the potential for increased use of polymers for flow control, study of their effects, especially on ultrasonic flow measurement equipment, is recommended.

Velocity Distribution

Although a significant effort has been made to define the relationship between average velocity along a horizontal chord or traverse, elevation of the chord or traverse, and the average velocity in the cross-section, much more work would be helpful in reducing the cost of flow measurements. Theoretical computations and laboratory and field observations have been made in the past, but a consolidation of known information, reinforced with selected additional data, would be quite useful, since many of the flow measuring devices infer average velocity from point or chordal measurements. This is particularly true with respect to ultrasonic flow measurements, where the average velocity along a chord or traverse between two meter probes is measured. Further knowledge of these relationships would also be useful with other flow measurement devices where flow is computed from the product of average velocity in the cross-section and the cross-sectional area.

APPLICATIONS RESEARCH

The state of the art and technologies are now at hand to allow the development, based on already established building blocks, of improved flow measuring devices for application to the storm and combined sewer problem. A few examples will be discussed.

Automated Dye-Dilution Devices

As discussed in Section VI, dilution techniques are very promising for application to the measurement of storm or combined sewer flows, especially in view of the new fluorescent dyes now available. Suitable equipment for either controlled-rate or slug injection of dye solutions is available. Automatic sampling equipment to allow reliable gathering of representative samples and fluorometers for automatically measuring dye concentrations are also available. There has even been work done on laser stimulation of fluorescence which could allow remote observation of dye concentrations without direct contact with the flow. Present integrated circuit technology would allow automatic conversion of dye concentrations to flow rates, in digital form, for indicating and recording and transmitting to central locations. It is even possible to develop a portable, battery-powered version that could be used for field calibration of existing flow measurement devices. It is recommended that a project to integrate these building blocks into an automatic flow measurement device be established, with emphasis on portability.

Portable Ultrasonic Devices

Sufficient field experience is now available to demonstrate the utility of ultrasonic equipment for the measurement of sewage flow, including stormwater and combined sewage. Development of portable equipment could expand the usefulness of this kind of flow measurement device to measurements of the miscellaneous type, such as in infiltration studies, to check the effluent from industrial plants, and for many other purposes.

Basically, ultrasonic flow measurement equipment is adaptable to compact packaging, as no large, heavy parts are required, even for measurements of large flows. Three separate packages might be developed - a level gage, several sets of meter probes, and associated electronic instrumentation. Provision should be made for installing the probes either inside or outside of closed conduits. Again, the fundamental building blocks are at hand, and it is recommended that such a project be initiated as soon as possible.

New Flumes

As noted in Section VI, there has been extensive research work performed on a variety of new flume configurations, with resulting designs that offer wider ranges, greater self-scouring characteristics, better submerged performance capabilities, etc., as compared to the more traditional designs, especially the Parshall flume. It is recommended that a project be established to consolidate the existing information on these efforts and, based upon this, to develop a flume possessing the most advantageous attributes in light of present day technologies and the storm and combined sewer application. For example, it might happen that a trapezoidal cutthroat flume with an automatic, electronic dual head comparison (Hb/Ha) and critical/submerged/pressurized flow algorithm shift integrated circuit card would offer great promise. Such a design is totally within the present state of the art and could be effected at a reasonable cost.

Ultrasonic Level Gages

As secondary elements in flow measurement devices, ultrasonic level gages show considerable promise for the storm and combined sewer application. They obviate the self-cleaning requirements of many secondary elements, offering the advantage of nc requirement for contact with the flow stream whatsoever. Their use has been fraught with difficulty, however, especially in settings such as a manhole application. The problems, from discussions with various field and applications engineers, would appear to stem mostly from spurious or false signal returns due to echoing from the installation structure. The problem has been encountered in many applications, e.g., the Rochester project, and has been independently solved (or apparently so) almost as many times. For example, the USEPA National Field Investigation Center, Cincinnati, has experienced such problems with different makes of equipment and has developed an inexpensive modification that apparently corrects the problem. It is recommended that a project to review the history of such experiences, including problem and solution descriptions, be prepared and procedures developed for the use of ultrasonic level gages in such applications.

DEMONSTRATION RESEARCH

There are several flow measuring devices, either presently available or virtually ready to be introduced, that offer considerable promise in the storm and combined sewer application. However, information about their use in such a setting is lacking, but could be gained from testing in a suitable facility as discussed earlier or from other field use such as a demonstration as an adjunct to an on-going project; thus, definite recommendations as to their suitability or fitness as storm or combined sewer flow measurement devices can be made. Some of these will be briefly discussed.

Venturi Meter/Flume

These flow measuring devices are designed to operate under both open-channel flow and full-conduit flow under pressure. Under open-channel conditions, the meters act as supercritical flumes, but when completely filled and under pressure, they behave more like modified venturi meters. For open-channel flow, only the depth at a single (usually upstream) measuring section is required. When the pipe is flowing full, and is under pressure, the flow is a function of the difference in the upstream head and the head at, say, the meter throat or an exit head. Two such devices have been recently developed - one by Dr. Harry G. Wenzel, Jr. at the University of Illinois, and one by George F. Smoot of the U.S. Geological Survey.

The 20.3 cm (8 in.) diameter test meter designed by Dr. Wenzel has been sufficiently laboratory tested, but has not undergone field experience to evaluate its self-cleaning characteristics and its hydraulic performance. It is recommended that a prototype meter of larger size, at least on a 61 cm (24 in.) diameter line, be tested in an actual combined sewer in line with an accurately calibrated meter of another type.

Several similar flumes designed by George F. Smoot for the U.S. Geological Survey have been installed in storm or combined sewers. However, there has not yet been sufficient field experience to allow adequate evaluation of them. It is recommended that a flume of this design be installed (preferably) in line with the meter designed by Dr. Wenzel and an accurately calibrated meter of another type for further evaluation.

Combination Thermal Flowmeter

Two thermal flow tube meters are manufactured by the Thermal Instrument Company, one for measurement of flow in pipes that are flowing full and another for flow measurement in partially filled pipe. Although discussed earlier, the principle of operation of these meters is described briefly as follows:

"A sensing element located on the outside of the flow tube is energized with a small amount of electrical energy (less than one watt). The heat conducted off this element, by the flow stream, is directly proportional to the mass flow rate of the fluid.

Additional sensing elements are located on the tube to compensate and correct for the effects of fluid and ambient temperature."

For measuring flow in partially filled conduits, a liquid level sensor is placed on the outside of the unobstructed pipe, in addition to the velocity measuring sensors.

Very little experience has been gained with this type of flowmeter in measurement of sewage. Meters are now in operation on 50.8 cm (20 in.) pipes carrying recycled pulp wastes. There is said to be no upper limit on the size or range of these meters.

Because of the obvious potential advantages of such nonobstructing meters, it is recommended that they be evaluated in a line of moderate size, but under conditions of both open-channel flow and full flow under pressure. The test meter would be placed in line with a flow measuring device of another type with proven accuracy.

Self-Calibrating Acoustic Level Gage

The "Aquarius" acoustic level gage described in Section VII offers many apparent advantages over more traditional ultrasonic level gages as a secondary element in a flow measurement system. These include: complete independence from all environmental effects; almost an order of magnitude greater accuracy than presently available; a low production cost; portability, which includes the promise of outstanding battery life (up to one year); and immediate computer compatibility, owing to its advanced, all-digital electronic design. At this time, however, the device is so new that virtually no data (outside the laboratory) are available to substantiate these promises in a field setting. It is recommended that one of these devices be procured and installed, at a site with a suitable primary device, alongside a proven head sensor in order to demonstrate its real capabilities in a field setting.

High Range Open Flow Nozzle

The H-series flumes (or open-channel flow nozzles), that were developed by the U.S. Department of Agriculture, hold considerable promise as primary devices for successfully measuring storm and combined sewer flows at many sites, as discussed in Section VI. In view of their low cost and very wide measurement range, it is recommended that a project be initiated to: (a) gather available information on the various flumes of this type and other open flow nozzle designs; (b) analyze this design; and (c) fabricate and test such a primary device.

SECTION X

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